

LAL ON
NR...4

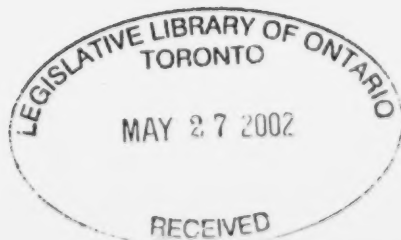
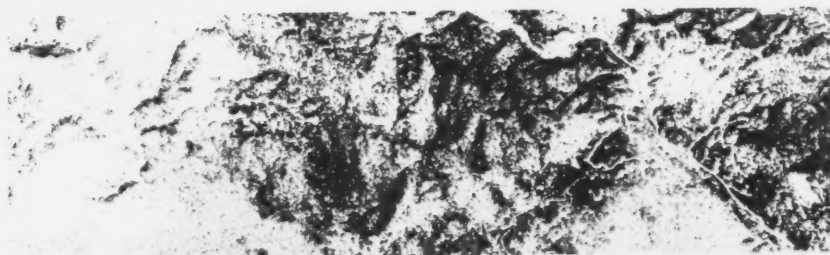
F149
c.2

Forest Research Information Paper No.

149

Emulating Natural Forest Landscape Disturbances: Concepts and Applications

Popular Summaries



Ontario
Forest
Research
Institute

Forest Research Information Paper No.

149

Emulating Natural Forest Landscape Disturbances: Concepts and Applications

Popular Summaries

*An International Science Symposium
May 11-16, 2002*

Compiled by

Lisa J. Buse
Ajith H. Perera

2002

Ontario Forest Research Institute
Ontario Ministry of Natural Resources
1235 Queen St. E., Sault Ste. Marie, ON
P6A 2E5 Canada
Tel. (705) 946-2981 Fax (705) 946-2030

National Library of Canada Cataloguing in Publication Data

Main entry under title:

Emulating natural forest landscape disturbance: Concepts and applications
popular summaries

(Forest research information paper, ISSN 0319-9118; no. 149)
ISBN 0-7794-3063-8

1. Forest landscape management. 2. Ecological disturbances.

I. Buse, Lisa J. (Lisa Jean), 1962- . II. Perera, A. (Ajith). III. Ontario Forest Research
Institute. IV. Series.

SD387.L35 2002 634.9'2 C2002-964000-8

© 2002, Queen's Printer for Ontario
Printed in Ontario, Canada

Single copies of this publication
are available from the address below.

Ministry of Natural Resources
Ontario Forest Research Institute
1235 Queen Street East
Sault Ste. Marie, ON
Canada P6A 2E5

Telephone: (705) 946-2981
Fax: (705) 946-2030
E-mail: information.ofri.@mnr.gov.on.ca

Cette publication scientifique n'est
disponible qu'en anglais.



This paper contains recycled materials.

Abstract

Buse, L.J. and A.H. Perera (comp.). 2002. Emulating natural forest landscape disturbances: Concepts and applications. Popular summaries. Ont. Min. Nat. Resour., Ont. For. Res. Inst., For. Res. Info. Pap. No 149. 100 p.

This information paper provides a compendium of summaries of presentations from a May 2002 symposium on emulating natural forest landscape disturbances (ENFD). The concepts, challenges, and potential consequences of implementing ENFD at the landscape level in forest management are discussed from several viewpoints. In addition, 10 case studies from across northern and central North America provide some practical applications of the concepts behind ENFD.

Acknowledgements

We thank Terri Weaver for administrative support and organizing author correspondence and Trudy Vaittinen for graphics and desktop publishing support. The financial support of the Ontario Ministry of Natural Resources and the Canadian Forest Service is gratefully acknowledged..

Table of Contents

Concepts

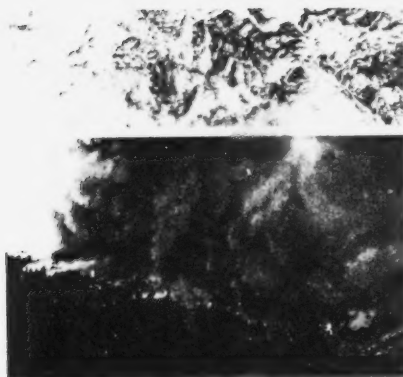
Emulating Natural Forest Landscape Disturbances: Overview and Context	11
Emulation of Natural Forest Disturbance: What does this mean, and how closely does management-induced disturbance duplicate the ecological effects of non-human forest ecosystem disturbance process?	15
Concepts and Approaches in Predicting Natural Forest Landscape Disturbances	19
Predicting Fire Regimes at Multiple Scales	23
Predicting Forest Insect Disturbance Regimes for Use in Emulating Natural Disturbance	27
Emulating Natural Forest Disturbances: From Policy to Practice in Ontario	31
Emulating Natural Forest Disturbances: Silvicultural Concepts and Applications for Silvicultural Systems in Forests in the Northern Great Lakes Region of the United States	35
Natural Disturbance Patterns and Forest Harvesting in the Western Boreal: From Concept to Practice	39
Ecological Basis for Emulating Natural Disturbances in Forest Management	43
A Conservation Biologist's Perspective on Emulating Natural Disturbance Management of Boreal Forests	47
What Are the Economics of Emulation Forestry?	51
Expectations and Consequences of Emulating Natural Forest Disturbance: A Forest Utilization Perspective	55

Case Studies

Presettlement Forest Cover in Northeastern Ontario	59
Using Natural Fire Regime-Based Criteria to Evaluate Forest Management in the Oregon Coast Range, USA	63
Using Insect-Caused Disturbance Patterns in Northern New Brunswick to Inform Forest Management	67
Spatial Simulation of Forest Fire and Timber Harvesting in Missouri Ozark Highlands	71
Spatial Simulation of the Large-Scale Forest Fire Regime in a Boreal Landscape	75
Emulating Natural Forest Patterns in the Inland Northwest, USA	79
Implementing Natural Disturbance-Based Management in the Black-Spruce Forest of Northwestern Quebec: From Ideas to Reality	83
Emulating Natural Forest Disturbances in the Wildland-Urban Interface of the Greater Yellowstone Ecosystem	87
Simulating Forest Fire Regimes in the Canadian Rocky Mountain Foothills	91
Empirical / Statistical Approaches to Modelling Wildland Fire in the Pacific Northwest, USA	93

Posters

Poster Presentations	99
----------------------------	----



CONCEPTS

Emulating Natural Forest Landscape Disturbances: Overview and Context

Ajith H. Perera and Lisa J. Buse

Ontario Forest Research Institute, 1235 Queen St. E., Sault Ste. Marie, ON, P6A 2E5 Canada Tel.: (705) 946-2981; E-mail: ajith.perera@mnr.gov.on.ca

Background

Emulating natural disturbances is an increasingly popular forest policy and management paradigm. It is referred to by many terms: managing within the historical range of variation (HRV) or the bounds of natural variation (BNV), emulating natural forest disturbance (ENFD), emulation silviculture (ES), or ecological forestry. Ontario is one of, if not the only, place where the practice of ENFD is part of resource management legislation and policy. However, this concept is also being evaluated, and in some places incorporated into aspects of resource management, across North America including British Columbia, Alberta, Quebec, and New Brunswick in Canada as well as in the Pacific Northwest and northeastern United States.

The concept of ENFD is not new. Natural forests have been always been the implicit null model for research and management. For example, in forestry research it is customary to use non-disturbed *natural* forest areas as experimental controls, to compare effects of treatments. In forest management we use community and site classifications that are based on the *natural* forest, rely on *natural* regeneration in some silvicultural systems, and view old growth as an important ecosystem because it occurs *naturally*. One difference is that with ENFD the null model is a disturbance process that may appear as *destructive* (from an environmental perspective), *risky* (from an economic perspective), *non-benign* (from an ecological perspective), and *unattractive* (from a public perspective), albeit natural.

The implicit (presumed) basis of *following nature* is that forest ecosystems are naturally sustainable, disturbances are an intrinsic part of nature, and therefore, by following natural disturbances in forest management, we ensure ecological sustainability. Logically, this argument is strong and appears irrefutable. Moreover, it is intuitively appealing given that the goal of *sustainability* is ambiguous and elusive.

While ENFD appears to be a logical and robust approach, the concept and its applicability are complex and need scrutiny. Our goal in this paper is to describe the ambiguities and varying expectations around ENFD at landscape scale by focusing on the following questions:

- What exactly does *emulating* mean?
- Do we understand the processes we are trying to emulate?
- Is ENFD a viable management option?

What Does Emulating Mean and What Do We Emulate?

The act of emulation can range from one extreme of absolute mirroring or mimicry (i.e., repeating natural disturbances exactly), to another of mere *learning from nature* (i.e., using nature only as a guide and selecting which aspects/effects to emulate). A second question is what exactly are we trying to emulate? For example, what is a natural disturbance? Does it mean natural forest processes

excluding human effects or including human effects as a part of nature? Does natural means what happened in some reference point in history (e.g., pre-settlement) or what can naturally happen at present and in future? Selecting one of the above premises over the others may lead to significantly different contexts and assumptions. Even perfect ecological knowledge may not provide answers to the above questions because of their socio-economic and cultural implications. However, given the many possible combinations in terms of what emulation might mean and how it might be implemented in resource management, clarity in terminology and expectations of ENFD is *a priori* to research, policy development, and practice.

Moreover, which natural disturbances should we emulate (e.g., fire, flooding, animal grazing), at what spatio-temporal scales (e.g., a rare thousand square kilometre fire, frequent tree-fall gaps), at what intensity (e.g., low-intensity ground fires, catastrophic insect epidemics), and where/when (e.g., randomly or with spatial and temporal biases)? The answers to these questions lie in the adequacy of our understanding of disturbances, and more importantly, their effects in forest landscapes. The well-studied field of forest disturbance ecology can provide a wealth of knowledge and insight through syntheses and judicious extrapolations of stand-scale information. Even so, serious consideration must be given to examining and understanding natural disturbances with respect to ecological scale and hierarchy.

Spatial and temporal portrayals of natural disturbances are essential if they are to be emulated. Is the ecological science and knowledge sufficiently mature to produce templates of natural disturbance regimes? For example, what minimum elements (e.g., intensity, temporal frequency, spatial probability, extent, causal/ hindrance factors) are required to describe a disturbance regime comprehensively? The current profusion of methods available for predicting natural

disturbances is generating some confusion. Is the ecological community at large aware of the fundamental differences in these approaches? For example, how would a description of a pest epidemic regime differ if it were predicted using an empirical model versus a mechanistic model, or a deterministic model versus a stochastic model? Alternatively, how should the historical evidence be used? What are the *bounds of natural variation*? Do we have adequate historical knowledge and documentation to assess this? At this stage in the evolution of ENFD, a general synthesis of the approaches for predicting natural forest disturbances is essential to develop standardized templates of natural forest disturbance regimes, and provide rigorous answers to these questions.

Is ENFD a Viable Management Option?

What knowledge is necessary to make ENFD a viable management concept? First, are the scientific principles of ENFD clear and acceptable to forest managers and other stakeholders? It is imperative that the basic ENFD tenet of "forest ecosystems are naturally sustainable" is elaborated, relying on concepts of disturbance ecology (e.g., ecosystem perturbation, resilience/tolerance, spatio-temporal scale, and stochasticity) in order to provide a credible science foundation and convince practitioners and stakeholders of its legitimacy as a management paradigm. Secondly, what are the various ecological, economic, and social expectations from ENFD? Are these expectations rational and congruent? Is ENFD a panacea for all forest management problems as perceived by its proponents? Explicit articulation of such implicit premises of ENFD is essential to avoid misconceptions and conflicts among stakeholders.

Many aspects of the operational feasibility of ENFD require detailed inquiry. For example, do we emulate the ecological processes that occur during

natural disturbances (e.g., fuel reduction and nutrient release by fires) or the outcome (e.g., post-disturbance structural and compositional features) through forest management? Are natural disturbances emulated at all spatial and temporal scales, or only at selected ones? If the latter, how do we choose?

What indicators signal success in emulating natural disturbances? These indicators will depend on answers to some of the above questions and will likely require discussion among stakeholders. What are the range of ecological, economic, and social consequences and risks associated with ENFD? Are

these reasonable and acceptable? Can existing forest management goals and practices be applied to complement ENFD? Do other environmentally, socially, and economically acceptable alternatives to ENFD exist? Answers to these questions are required to decide the feasibility of ENFD.

The concept of ENFD is still in its infancy, and thus is surrounded by many ambiguities and a plethora of questions. Therefore, scrutiny of many facets of its principles and feasibility is required to instill scientific rigour to the concept and to enable practitioners to make sound decisions in embracing ENFD.

NOTES

Emulation of Natural Forest Disturbance

What does this mean, and how closely does management-induced disturbance duplicate the ecological effects of non-human forest ecosystem disturbance process?

J.P. Kimmins

Department of Forest Sciences, University of British Columbia, 3041 – 2424 Main Mall, Vancouver, BC V6T 1Z4 Canada Tel: (604)822-3549; E-mail: kimmins@interchg.ubc.ca

The most important characteristic shared by all biological systems is that they change. They do so because of internal (autogenic) processes, and also because of external physical (allogenic) or biotic (biogenic) factors. Autogenic change is a consequence of individual plant, plant population, and biotic community processes, and their effects on the soil and microclimate. It is initiated or altered by external processes that accelerate, regress, or otherwise change the rate and pattern of autogenic changes that are expected for the forest in question.

Forest ecosystems change as a result of autogenic processes that take any particular stand of trees and other organisms through a series of structural changes over time (stand dynamics), and then replace this biotic community by another (ecological succession) that also goes through the phases of stand dynamics. "Disturbance" in the context of forest ecosystems is defined here as the change in rates and patterns of expected autogenic change caused by allogenic or biogenic factors or events. Change driven by factors internal to the ecosystem in question is not considered to be disturbance.

The human population doubled over the past 40 years, an increase of three billion. It has increased by a factor of 6 over the past 2 centuries. This dramatic increase in our species abundance has been accompanied by a rapid acceleration in the scale and severity of human impacts on the world's forests. In some cases, these effects have constituted a new form of biogenic disturbance. In

others, the effects have taken the form of changes in the frequency, scale, and severity of allogenic and non-human biogenic disturbance. This has resulted in substantial losses of global forests (estimated to be as much as 40%) and significant changes in the age, species composition, productivity, and non-timber values of the remaining 60%.

Organisms require a variety of resources and conditions if they are to survive, reproduce, and maintain their species. For terrestrial organisms, these resources and conditions are largely a function of the plant community. The "coarse filter" approach to sustaining the diversity of forest organisms asserts that the most plausible strategy for sustainability is to maintain the historical range of variation in tree age, time since disturbance, structure, species composition, soil condition, and landscape pattern. However, humans have altered natural disturbance regimes (e.g., fire, herbivore browsing), and the consequences of the more severe and large scale natural disturbances are socially, politically, and economically unacceptable. Consequently, the best way to maintain natural stand and landscape patterns, species composition, and ecosystem conditions and functions is to emulate, through management, the ecological effects of natural disturbances that no longer occur but are considered socially acceptable and desirable.

In the face of continuing human population growth, a new relationship between humans and forests will be necessary if we are to sustain the full range of values that forests have provided in the past. There are many possible models for this

relationship, including ecosystem management, adaptive management, zonation, variable retention, maintenance of natural range of variation, and emulation of natural disturbance. These can be applied as regulation-based or results-based approaches, and in various combinations. Each approach has its own strengths and shortcomings, and it is probable that different combinations will be required at different times and places. The emulation of natural forest disturbance approach (ENFD) provides a useful template for designing a new relationship for those forests in which the frequency of natural stand-replacing disturbance is similar to the anticipated frequency of timber harvesting. The combination of ENFD with other approaches can also be useful in redesigning management of forests in which severe large-scale disturbance occurs at intervals that are multiples of forest harvest cycles (rotations).

ENFD is about balancing the severity, scale, and frequency of forest disturbance with the innate or management-assisted recovery of ecosystem conditions and functions – a balance that is captured in the concept of ecological rotations (ER). Because different forest values have different ER's, different forest areas should be managed at different disturbance frequencies (zonation), or, using space-for-time substitution, ecosystem management combined with variable retention (VR) can be used to maintain values with different ER's within a particular harvest area – although this may or may not emulate the effects of natural disturbance spatially.

In some types of forest, ENFD will result in a relatively small range in disturbance type, frequency, spatial scale, and severity, with the result that a relatively narrow range of forest ages, patch sizes, and seral stages is maintained across the landscape. In some other types of forest, ENFD will require a wide range of disturbance types, patch size, severity, and frequency, resulting in a wide variation in landscape pattern, ecosystem condition, and seral

stage. In yet other forests, ENFD will involve differences over time in disturbance regimes: a forest may be clearcut and burned to produce early seral conditions, maintained as an even-age forest with commercial thinning for a conventional rotation period, and then subject to a sequence of partial harvests to produce a more complex stand structure before a subsequent more severe disturbance. This would sustain a much wider range of seral conditions and biological diversity in any particular stand over time and across the landscape than either the traditional fixed rotation and repeated silvicultural system of past European/Scandinavian forestry, or the low impact, "soft-touch" forest harvesting that is advocated by many public groups and some biologists and non-ecological scientists.

Contrary to popular public opinion and the assertion of some environmental groups, appropriate disturbance regimes are not only part of the ecology of most forests, but are ultimately necessary to maintain a wide range of desired forest values. In some forest types, the long-term sustainability of closed forest conditions may require periodic severe disturbance, unless management interventions are so intensive as to constitute "forest gardening". In many cool and humid northern and high elevation forests, most tree species are a less competitive plant life form than vegetatively reproducing, rhizomatous shrubs belonging to the heather family (Ericaceae), or sphagnum mosses. Based on the concept that in the long run the most competitive plants are those that can tolerate and survive the lowest level of resources, these species will eventually dominate if soil resource availability declines in the absence of disturbance. Ericaceous woodland or treed sphagnum muskeg is the probable eventual climax vegetation of many northern forests in the long-term absence of disturbance and climate change. The presence of closed, productive forest over much of our northern and sub-alpine unmanaged

landscapes is a reflection of past natural disturbance that has tipped the competitive balance in favour of trees by making adequate soil resources and light available.

A major task and responsibility for forest scientists is to describe and understand natural forest disturbance so that forest management can be designed to emulate the effects of processes that are no longer permitted by society to operate. An equal responsibility is to communicate this understanding, and the ecological rationale for ENFD, to the public in order to secure a social license for forest management and forest disturbance that respects nature's ecological diversity and sustains biological diversity and other social values.

Nature can be compared with ecological theatre. The biological potential of an area is determined ultimately by the climate, soil, topography, geology and allogenic disturbance factors (e.g., wind, fire, landslide, flood). This ecological diversity is analogous to the theatrical stage – the setting of which determines which play can be staged. The ecological play that is acted out on this ecological stage is analogous to the successional development of the ecosystem following some allogenic or biogenic disturbance; the acts of the play are

analogous to the seral stages of ecosystem recovery from disturbance. The ecological actors – the species and hence species measures of biodiversity – depend on which act (seral stage) of which ecological play (which successional pathway of recovery from which disturbance) is occurring on which ecological stage. If we wish to manage forests to sustain for future generations the many forest values that we believe they will want and need, we must be ecological stage managers, ensuring that the appropriate ecological play is acted out on each ecological stage, including all acts of the play needed to ensure that all desired actors appear on stage at some point of the play.

Forestry is first and foremost about people – not ecology or biodiversity. Today, informed forest managers and society in general insist that ecology and biodiversity be the foundation on which economic and socially desirable forestry is built. This is because people now recognize the importance of this ecological/biological foundation. It is a responsibility of forest scientists and managers to ensure that the public recognizes the pivotal role of disturbance in the sustainability of forest values, so that foresters are permitted to emulate natural forest disturbance to the degree that society can accept.

NOTES

Concepts and Approaches in Predicting Natural Forest Landscape Disturbances

Roger Suffling¹ and Ajith H. Perera

¹Faculty of Environmental Studies, University of Waterloo, Waterloo, ON, N2L 3G1 Canada Tel.: (519)888-4567 x3184; E-mail: rcsuffli@uwaterloo.ca

²Ontario Forest Research Institute, 1235 Queen St. E., Sault Ste. Marie, ON, P6A 2E5 Canada

Introduction

Clear understanding of natural disturbances is a prerequisite for embracing the notion of emulating natural forest landscape disturbances. This task is not trivial because natural disturbance processes are inherently complex, and our perception of what is *natural* is often subjective. The semantics of disturbance and proliferation of methods used to study it further confuse this topic. In this presentation, we shall review concepts and approaches commonly used in predicting natural disturbances with the goal of clarifying the principles.

How Natural is Natural?

There are differences in the perception of what is *natural*. Does it imply that humans are absent or excluded from the forest landscapes, or are humans an integral and traditional part of forest landscapes? The human-excluded perception of *natural* provides a relatively simple reference point in an ecological sense, but may not be a very practical view. Conversely, if human influences are included in defining *natural*, our view will encompass socio-economic and cultural biases, in addition to ecological reasoning, leading to more complicated scenarios.

Natural Forest Landscape Disturbances: How Simple are They?

Even without human influences, all forest ecosystems are universally disturbed. Ecologists have been describing and defining natural disturbances for nearly a century, using various terminologies. For example, Picket and White (1985) defined disturbances as a "relatively discrete event in time that disrupts ecosystems...and changes resources, substrate availability, or the physical environment." However we define such disruptions of ecological process, we must recognize the multi-dimensionality of natural forest disturbances. The causal factors range from simple (e.g., flooding) to complex (e.g., beaver flooding and herbivory); temporally rare (e.g., Tsunamis in coastal forest) to frequent (e.g., surface fire); spatially rare (e.g., Tunguska-type meteorite events) to common (e.g., insect epidemics); autogenic (e.g., old age tree gaps) to allogenic (e.g., hurricane); and biotic (e.g., fungal tree mortality) to physical (e.g., avalanche). This multi-dimensionality can be simplified by understanding the ecological scale and hierarchy of disturbances. For example, a single tree fall would be catastrophic, rare, and allogenic to a small moss ecosystem, while being insignificant, common, and autogenic to a large forested landscape. Conversely, a very large ice storm could be catastrophic, rare, and allogenic to both the forest landscape and the moss ecosystem nested within it.

Most natural disturbances appear to be controlled by different factors occurring at different scales in time and space. For example, climatic trends at regional scales, topographic and land cover patterns at sub-regional scales, and fuel availability at stand-scales may control forest fires.

How Can We Predict and Characterize Natural Forest Landscape Disturbances?

Some natural disturbances can be forecast in time; for example, the cyclical occurrence of forest insect infestation. Other disturbances are predictable spatially; for example, the likelihood of a riverside forest being flooded at various elevations. Still other events can neither be forecast precisely in time or in space, as is the case with most fires. Thus predictions can usually only *describe* and *characterize* natural disturbances over time and space, rather than prophesying exact events. Disturbances can be described as individual events (e.g., size of one fire, intensity of one ice storm) and as comprehensive regimes (e.g., a population of multiple disturbance events). The regime recognizes temporal and spatial pattern of natural disturbances that can be characterized and analyzed statistically.

A disturbance regime can be typified primarily by force or intensity of the causal agent (e.g., wind speed of hurricane), morphology (e.g., sizes of fires), spatial pattern (e.g., orientation of wind throw), and interval between disturbance events (e.g., of floods, fires). Second, the impact of the disturbance events on biotic and physical environment, termed 'legacies of disturbances', can be used to characterize a disturbance regime (e.g., severity of fires). The array of physical, biotic, and sometimes chemical factors involved with initiation, progress, and extinguishment of disturbances make them endlessly and sometimes unpredictably variable in their effects. Third, conditions existing before an event also have a profound influence on

the outcome. Finally, it is essential that descriptions of disturbance regimes include this stochasticity (central tendencies, extremes, and probability distribution functions). For example, a fire disturbance regime may be described in terms of the probability distribution of fire sizes, the spatial tendency of occurrence of fires, or the variance of fire return interval.

There are 2 fundamental approaches to predicting natural disturbances: Natural history methods, which have been in use for many decades, and the scenario-simulation methods, which have gained popularity recently. Natural history methods reconstruct historical natural disturbances as reference conditions using various types of evidence, as archeology does for human history. These sources of evidence include the structure and composition of the modern forest ecosystem, historical documents such as survey records, land registries; cultural evidence such as photographs, paintings, anecdotal writings; and palynological, dendrochronological, and ethnobiological records of disturbances. Portrayal of historical natural disturbances and their use as reference or benchmark conditions generally have great social appeal. Natural history methods often yield single-event predictions (spatially and temporally) as opposed to comprehensive disturbance regimes. Moreover, errors in predictions cannot be readily estimated due to limitations in historical records.

The scenario-simulation methods use abstraction or modelling techniques to describe natural disturbances, based on information collected previously. These simulation models can be categorized in many ways. For example, empirical models employ statistical extrapolations of previously observed natural disturbances (e.g., size-class distribution of fire), in contrast to mechanistic models, which use knowledge-based processes (e.g., weather and fuel-aided fire spread) to simulate natural disturbance processes. Most models are,

however, hybrids containing both empirical and mechanistic components. In general, simulation-modelling methods yield comprehensive disturbance regimes, with estimable errors of predictions. In addition, these predictions are incrementally improvable as science and technology advance. However, the abstract nature of simulation model results hinders their popular acceptance compared to natural history methods.

No single approach or method is likely to be sufficient on its own, and each must be examined in terms of how it contributes to the basic requirements for predicting natural disturbances. For instance, palynology is useful for describing

previous species composition but, though improving, is inherently poor at spatial descriptions of disturbances. Addressing the stochasticity of natural disturbances is a primary requirement in capturing the variability of disturbances. Making predictions scale-explicit is just as important because all natural disturbances and their consequences are scale dependent with respect to temporal, spatial, and ecological resolution. Finally, given the rapid proliferation of methods of predicting natural disturbances, all methodological assumptions should be explicitly described such that users can determine the contextual limitations of the predictions.

NOTES

Predicting Fire Regimes at Multiple Scales

Robert E. Keane, Russell E. Parsons, and Mathew G. Rollins

USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory,
P.O. Box 8089, Missoula, MO, USA, 59807. Tel: (406)329-4846; E-mail: rkeane@fs.fed.us

Introduction

Temporal and spatial descriptions of historical wildland fire processes are critically needed if future land management involves the use of silviculture and prescribed fire to emulate past fire regimes. Characterizations of native fire regimes will dictate the planning and design of silvicultural treatments, such as target stand structures and harvest guidelines. They can also be used to prioritize and schedule future treatments based on fire frequency and severity. An expression of fire frequency can be used to guide the scheduling of fire treatments and periodicity of landscape assessments. Last, fire regime maps can be used to develop input parameters for landscape models to simulate effects of alternative management strategies on landscape dynamics.

The classification and prediction of fire regimes are difficult, problematic, and costly tasks that can be discouraging to many land management agencies. Fire regime prediction often requires extensive expertise in fire ecology, fire history sampling, statistical analysis, and Geographic Information Systems (GIS). This paper presents the challenges of predicting fire regimes and then reviews 3 strategies (GIS modelling, statistical modelling, and simulation modelling) and 3 approaches (stochastic, empirical, and biophysical) for describing, predicting, and mapping fire regimes using examples from the literature and also describes an original modelling experiment. Physical, ecological, and administrative barriers and limitations to fire regime prediction are also discussed, such as inadequate field sampling, lack of fire history artifacts, conflicting scale of application, and inadequate error estimates.

Review of Methods

A variety of techniques and methods have been used to predict fire regimes for stands and landscapes. We describe these techniques by the approach and strategy used to derive the fire regime estimate. The **approach** is a general description of the methods used to create fire regimes and we have identified three main approaches: 1) stochastic, 2) empirical, and 3) physical. The **stochastic** approach uses probabilities to quantify or describe the fire regime. An **empirical** approach uses field data to derive deterministic relationships to represent the characteristics of a fire regime. The **physical** approach uses the formulations of basic physical processes driving ecosystems and landscapes to create fire regime descriptions. These approaches are not mutually exclusive and, in fact, the best fire regime predictive models are often created by combining approaches. Because of this, it would be tremendously difficult to classify models by approach. For example, many probabilistic relationships are derived from empirical data describing a physical process (e.g., probability of a lightning strike). In this paper, we present the strategy used to create the predictive model as further descriptive and classification criteria.

The **strategy** is described by the set of tools and protocols used in the development of fire regime predictive models. We have identified 3 broad strategies: 1) classification, 2) statistical analysis, and 3) simulation. The predictive models presented here can take many forms from simple classifications to empirical equations to complex mechanistic simulation models, depending on the strategy and approach. The **classification** strategy involves

assigning a fire regime category to the most appropriate category in related classification schemes, usually based on vegetation, biophysical settings, or climate. For example, a low severity, frequent fire regime may be assigned to the ponderosa pine cover type. The **statistical analysis** strategy uses the entire suite of multivariate statistical techniques, including regression, ordination, general additive models, and logistic regression, to create a fire regime predictive model that can be deterministic or stochastic. This strategy is easily the most popular because of its simple, data-driven approach. The most common and accurate spatial statistical analysis is the distillation of fire atlases (maps documenting the spatial extent and date of past fire events) into a representation of fire frequency and severity. The **simulation modelling** strategy uses stand or landscape models to simulate fire events and succession and generate some expression of fire regime. This strategy is somewhat new because recent advancements in computer technology have allowed an independent spatial simulation of fire spread coupled with weather and topography. There are usually 4 components in a landscape fire model: vegetation succession, fire ignition, fire spread, and fire effects.

We evaluated some of the approaches and strategies for developing fire regime maps using our own data set. Various combinations of the three approaches and strategies were used to create fire regime maps (fire frequency and fire severity) with identical properties (i.e., classification categories, map resolution, field data sets). The 50,000 ha White Sands Creek watershed in the Selway-Bitterroot Wilderness Area was used as the analysis landscape for this comparison. The plot data used in the analysis were collected in 1995 for lands surrounding the analysis watershed. The classification empirical approach strategy was used to create one set of fire regime maps from the rule sets used for the Interior Columbia River Basin. Another set of maps was created using discriminant

analysis and regression modelling on an extensive gradient-based field data set in a statistical empirical approach strategy. We then simulated several ecosystem process variables, such as net primary productivity, evapotranspiration, and soil moisture, for each plot and then these new variables were included in the discriminant and regression analyses to achieve a statistical physical approach strategy. Last, the LANDSUM landscape fire succession simulation model was used to generate fire regimes in a simulation stochastic approach strategy.

Challenges

Fire history field data are absolutely essential for a myriad of fire regime prediction tasks because they provide the only truth for understanding, predicting, and interpreting fire dynamics. First, field data are needed to design and describe fire regime classifications and resultant categories. They are also necessary for the creation of predictive equations using statistical techniques, and the subsequent validation and accuracy assessment of those equations. Geo-referenced fire history data (i.e., spatially located) are especially useful for fire regime map development and map accuracy assessment. Extensive field data sets can also provide insight and context into the causal mechanisms of fire regime dynamics. And last, fire history field data can be used to initialize, parameterize, and validate landscape ecosystem models of fire dynamics.

The primary challenge in predicting fire regimes is matching or determining the spatial and temporal scales that govern fire and landscape dynamics. Fire is a complex disturbance process manifest at many time and space scales, yet many fire regime studies attempt to describe fire dynamics at the stand-level across relatively small time spans. For example, wind and slope are the primary spatial coarse-scale, landscape processes responsible for fire pattern, yet most empirical fire regime predictive modelling

occurs at a stand level without accounting for downwind and upslope effects. Lightning dynamics is still another important and complex process that is rarely integrated into predictive fire regime models. Most fire regime predictive studies rely on data describing historical fire characteristics, but the associated scale of these data often does not match the scale of the analysis.

The inherent variability within a fire regime is ultimately responsible for landscape structure and composition. For example, variability in fire return interval is of utmost importance in assessing the degree of departure from historical conditions along with designing fire treatments, assessments, and schedules for landscape management. Fire pattern characteristics dictate the size and shape of future treatments that attempt to emulate natural fire. And, the range of fire severities experienced within a fire regime will guide treatment design and implementation. Yet, most fire regime models rarely characterize the inherent variability of the predicted variables of fire frequency or severity.

A major dilemma with most fire regime predictive efforts is that the models will become obsolete once predicted climate change becomes reality and future land use policies govern fire management. Future changes in climate will render most maps incorrect unless the models used to describe fire regime contain a link to climatic processes. It is essential that future fire regime predictive efforts integrate climatic variables into model design so that fire regime maps can be updated with new weather records. This emphasizes the importance of the simulation strategy in creating future fire regime maps because simulation models can be designed to be explicitly linked to detailed climate drivers.

Another challenge is designing useful fire regime classification categories for use across diverse local, regional, and national applications. The range of fire return intervals that define a frequency category may not be optimal across all landscapes in a region or across all spatial scales.

NOTES

Predicting Forest Insect Disturbance Regimes for Use in Emulating Natural Disturbance

David A. MacLean

University of New Brunswick, Faculty of Forestry and Environmental Management,
PO Box 44555, Fredericton, NB, E3B 6C2 Canada Tel: (506)458-7552; E-mail: macleand@unb.ca

Introduction

Insect outbreaks are a major natural disturbance in Canada and other regions. Timber supply losses caused by insects and diseases are about 81 to 107 million m³/year in Canada, or roughly one-half of annual harvest levels. Somewhat surprisingly, pest-caused losses are about 3 to 4 times the losses to wildfires, partly due to more salvage following fire. Sustainable harvest level for Canada's forests, estimated as the annual volume production rate at about 240 million m³/year, is only a little more than double the annual losses to pests (Table 1).

Which pests cause the biggest losses? Sterner and Davidson (1982) provided the following breakdown: spruce budworm 41%, wood decay 23%, hypoxylon canker 10%, aspen defoliators 7%, mountain pine beetle 5%, dwarf mistletoe 3%, spruce bark beetle 3%, and miscellaneous defoliators, bark beetles, and diseases the remaining 8%. Major budworm outbreaks in Canada began in about 1910, 1940, and 1970; see Figure 1 for New Brunswick.

Major insect outbreaks result in stand-replacing disturbances, while less severe insect damage often causes gap-replacing disturbances. In these cases, single trees or clumps of trees are killed, creating

gaps that permit regeneration. Categorization and analysis of insect-caused disturbance regimes can help to support forest management that is consistent with natural disturbance. It is somewhat questionable whether we can truly "emulate" insect-caused disturbance – there will always be differences between harvest and natural processes – but such analysis clearly can help to design (I prefer the term "inspire") both stand- and landscape-level disturbance.

Quantitative Assessment of Effects of Forest Insect Disturbances

In order to determine insect outbreak effects, we need methods to quantify and model the effects of defoliation or other insect damage on stand dynamics. Erdle and MacLean (1999) proposed a method to quantitatively assess forest pest impacts, which involved forecasting pest populations, defining the nature and extent of damage inflicted on trees by those populations, and translating the damage effects across scales, from tree to stand to forest. Central to this process were stand development forecasts that include tree-level

Table 1. Annual losses caused by pests and fire compared with annual harvest levels and sustainable harvest level (AAC) for Canadian forests

Disturbance	Volume lost (m ³ /yr)	Year
Pests	107,000,000	1977-81
	81,265,000	1982-87
Fire	24,600,000	1977-81
Harvest	180,000,000	1988
AAC	240,000,000	1980-88

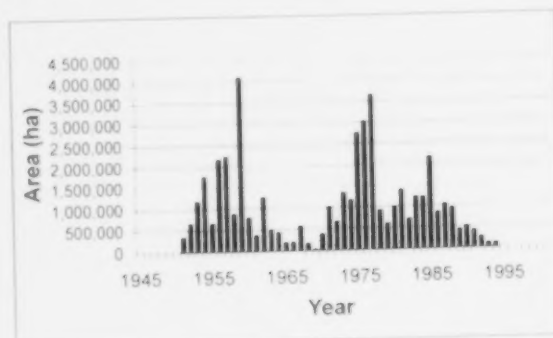


Figure 1. Moderate-severe spruce budworm defoliation in New Brunswick, 1945-1995

impacts and provide input to forest-level models. Calibration of stand growth models involved using 20 years of permanent sample plot data to define relationships between tree survival and growth versus defoliation.

The first requirement is to define pest incidence over time. In many cases it is very difficult to accurately predict the beginning of an outbreak, but scenarios of general outbreak patterns, based on historical data, can be used to determine "what if" effects of outbreaks. Incremental effects of pest damage are generally a function of 1) the severity of the damage, which can be measured, for example, as percent defoliation for defoliating insects; and 2) the vulnerability of trees being affected, which may result in differential response to a given damage level (Erdle and MacLean 1999). For example, a given level of defoliation may more strongly decrease survival in a mature balsam fir (*Abies balsamea*) than in an immature spruce (*Picea* sp.) stand (MacLean 1980). Stand growth models are a critical component of pest Decision Support Systems (MacLean 1996, MacLean et al. 2001).

Categorization of Natural Disturbance Regimes

In 1998, a group of ecologists in the Maritime Provinces categorized the natural disturbance regimes that occurred in the region (Clowater et al. 1999). The major disturbance agents included were fire, spruce budworm, windstorm, and continuous tree death (gap replacement). Each was categorized in terms of: 1) agent; 2) disturbance cycle (return interval) – continuous/ongoing, short (5-30 yrs), intermediate (31-60), long (61-100), and very long (101-1000 yrs); 3) extent – regional, multi-stand (101-500 ha), single stand (5-100 ha), and tree (within stand); and 4) post-disturbance stand condition – stand replacing (0-25% stand remaining), partial stand replacing (26-50% remaining), patch replacing (51-95% remaining), and single tree replacing (gap creating; 95-100% remaining). Categories included 6 fire regimes, ranging from very infrequent severe to frequent mild fires; 3 windstorm regimes; as well as the 3 budworm and 2 gap creation regimes shown in Table 2.

Table 2. Stand remaining following disturbance (%) as a guide to harvest removal.

Disturbance category	Severity	Stand remaining (%) - range	Stand remaining (%) - midpoint	Stand removed in harvest (%)
B1 Budworm – stand killing	Stand replacing	0-25	12.5	87.5 (75-100)
B2 Budworm – partial mortality	Partial stand replacing	26-50	37.5	62.5 (51-75)
B3 Budworm – minor effects	Patch replacing	51-95	72.5	27.5 (5-50)
G1 Gap creation – patch creation	Patch replacing	80-95	87.5	12.5 (5-20)
G2 Gap creation – natural stand dynamics	Gap replacement	96-100	97.5	2.5 (0-5)

Since budworm only influences host species (balsam fir, white spruce (*Picea glauca*), red spruce (*Picea rubens*), black spruce (*Picea mariana*)), harvest removals for categories B1-B3 only apply to the host species component.

The 5 disturbance regimes in Table 2 are being implemented experimentally on 2600 ha of forest in northern New Brunswick, Canada. Disturbance categories B1, B2, and B3 are based on the level of spruce budworm-caused mortality, varying based on the amount of balsam fir and spruce in the stand, and will involve harvesting on average about 87.5, 62.5, and 27.5% of the fir-spruce content. These are equivalent to stand-replacing, partial stand replacing, and patch replacing disturbances. Disturbance regimes G1 and G2 apply to tolerant hardwood stands (sugar maple (*Acer saccharum*) and yellow birch (*Betula lutea*)) and are essentially group selection and single tree selection treatments. These approximate gaps created by the death of small clumps or single trees, caused by, for example, blowdown, root rot, other insects, and old age.

Influence of Insect Disturbance Regimes on Forest Management

Insect outbreaks influence forest structure and composition at both the stand and landscape level. At the stand level, harvest prescriptions can be based upon removing an equivalent amount of trees to what would be killed by insects. At the landscape level, data about insect effects can help to set targets for species composition, age class distribution, patch size distribution, and connectivity. For example, the proportion of stands being killed by insects could be approximated by amount of forest harvested and regenerated to a younger age class, species composition changes created by harvest, and patch size and connectivity patterns can be implemented based on spatial harvest planning. Such a disturbance-based analysis must be tailored to stand types and regions; it is not transferable to other stand types or even necessarily to the same stand type in other regions.

Realistically, no jurisdiction or forest company will blindly emulate what insects do in killing forests over large regions. However, in some cases, stand-level harvest that approximates insect effects may well make ecological sense, particularly where it results in mixed species stands or multi-age class stands that otherwise would be rendered homogeneous by clearcutting. Analyzing insect effects at the landscape level in particular can be instructive in a coarse filter approach to conserving biodiversity. Insect-caused mortality influences species composition and age class distribution, while also determining patch sizes. Decision support systems (DSS) designed to assist in strategic planning of insect effects on AAC and harvest scheduling, or operational planning of insecticide application or restructuring forests to reduce losses, can also be used to determine spatial pattern effects of insect disturbance. The Spruce Budworm DSS (MacLean et al. 2000, 2001) is being used in this way in New Brunswick, to scale up effects from trees and stands to landscapes.

References

- Clowater, R. et al. 1999. Categorization of Natural Disturbances in the Maritimes. Forest Stewardship Council Maritimes Community Types Committee.
- Erdle, T.A. and D.A. MacLean. 1999. For. Chron. 75: 141-152.
- MacLean, D.A. 1980. For. Chron. 56: 213-221.
- MacLean, D.A. 1996. Can. J. For. Res. 26: 1731-1741.
- MacLean, D.A. et al. 2000. Comput. Electron. Agric. 27: 293-314.
- MacLean, D.A. et al. 2001. Can. J. For. Res. 31: 1742-1757.
- Stern, T.E. and A.G. Davidson. 1982. Forest insect and disease condition in Canada, 1981. Can. For. Serv., Ottawa, ON.

NOTES

Emulating Natural Forest Disturbances: From Policy to Practice in Ontario

John G. McNicol¹ and James A. Baker²

¹President, JGM Forestry Consulting, Thunder Bay, ON P7J 1B7 Canada, Tel.: (807)577-2699; E-mail: jmcn@tbaytel.net

²Science Advisor, Applied Research and Development Branch, Ontario Ministry of Natural Resources, 1235 Queen St. E., Sault Ste. Marie, ON P6A 2E5 Canada

Why a Policy to Emulate Natural Disturbance?

Ontario has adopted a policy to emulate natural forest disturbance for 2 main reasons: one is that it is a legal requirement under recent provincial legislation, and the other relates to an *ecological argument* based on observed differences between landscape patterns created by natural disturbances and those created by past industrial forest management.

The Legal Requirement

The legal requirement stems from direction provided by the Ontario Environmental Assessment Board's 1994 ruling after 5 years of hearings on the *Class Environmental Assessment by the Ministry of Natural Resources for Timber Management on Crown Lands in Ontario* (Timber E.A.) and the enactment of the Crown Forest Sustainability Act (CFSA) in 1995. During the five-year class environmental assessment (1989-1994), Ontario examined the environmental effects of timber management practices (access, harvest, renewal, protection), including considerable evidence discussion about the environmental effects of clearcutting and the size of clearcuts. The Ministry of Natural Resources' (MNR) position on clearcutting was that it was the most appropriate system for the many shade intolerant boreal tree species; its position on clearcut size was that they should follow natural disturbance size class tendencies (i.e., many small, some medium, and a few large) rather than a constant pattern of small cuts.

In their decision, the Environmental Assessment Board recognized the clearcut silvicultural system as an appropriate harvest and renewal system, particularly for boreal forests. Because of the concerns they had heard about large clearcuts, they put a 260-ha limit on clearcut size, but permitted exceptions as long as the biological or silvicultural rationale was included in the Forest Management Plan. The Board also acknowledged the need for a range of clearcut sizes to emulate the pattern of natural fire and directed MNR to prepare a guide providing direction on *harvest layout, configuration, and clearcut sizes*.

Shortly after the Timber E.A. Decision, the Crown Forest Sustainability Act (1994) was passed. One of principles of the Act was that *forest practices ... within the limits of silvicultural requirements, emulate natural disturbances and landscape patterns while minimizing adverse effects on plant life, animal life, water, soil, air and social and economic values*. The logic was that by trying to emulate natural landscape patterns, to the best of our understanding and ability, it is more likely that we will maintain ecosystem processes and thus biodiversity.

The Ecological Argument

Although both the Environmental Assessment Board direction and the CFSA contained an ecological rationale for changing the existing guidelines that influenced clearcutting, it became even more clear as evidence of differences between landscapes patterns created by stand-replacing fires and industrial forest management began to emerge

in the mid-1990s. Comparisons made across the boreal forest of cutovers and forest fire disturbance since 1950 demonstrated that the amount of edge created by forest management had been accelerating since the early 1980s compared to no increase in edge density for those landscapes affected only by wildfire. In northwestern Ontario, studies on moose populations and landscape patterns revealed that small clear cuts with buffer zones designed to create landscapes highly suitable for moose were perhaps not as productive as contiguous clearcut landscapes.

Until the moose habitat guidelines came into effect in 1988, there had been no guidance on clearcut sizes. Moreover, although the moose guidelines recommend a small range of clearcut sizes (80-130 ha) and directed that residual strips of forest be retained between cut clear patches, there was no restriction on the geographic extent of small clear cuts. What emerged in northwestern Ontario, was that not only were small patches being created that were quite unlike burned areas, but these small patches were dominating large areas of the landscape. At a finer scale, studies of patterns within burned areas demonstrated that there was considerable standing timber left in burned areas; primarily in the form of residual patches.

Implementing the Natural Emulation Policy

All forest management policies in Ontario are implemented through planning guidelines. Thus, the natural emulation policy was implemented by preparing a guideline that would ultimately be used by planners. MNR appointed a writing team in December 2000 to undertake the task of developing the guide that would address *harvest layout, configuration, and clearcut size* in a way that emulated *natural disturbances and landscape patterns*. The writing team included a representative from each of the academic, industrial, and environmental

communities as well as 4 MNR representatives.

In preparation for writing the guidelines it was necessary to establish a template of natural disturbance by fires for each region of the province. More than 2,000 fires (>200 ha) were analyzed for the period 1920-1950. This time period was used because fire suppression was assumed to be considerably less effective than post-1950 and therefore these fires were assumed to be more representative of a natural fire pattern. During the analysis of this database, frequency and area /size class information for each ecologically classified site region was developed to provide a statistical *picture of natural disturbance patterns*.

Through 21 meetings, 2 workshops, and 2 public reviews of drafts, the writing team could not find consensus on some landscape-level issues primarily dealing with clearcut size. Stand-level issues related to simulating fire disturbance structure were much less contentious. Agreement on an acceptable size range for clearcuts was difficult because of uncertainties about how well the historical data represented long-term fire patterns of 100s to 1000s of years and the environmental effects of large clearcuts.

The Forest Management Guide for Natural Disturbance Pattern Emulation

The essential elements of Ontario's new natural disturbance pattern emulation guide are:

- Eighty percent of cuts are to be less than 260 ha in the boreal forest (90% in the Great Lake-St. Lawrence/GLSL/forest). The number of cuts > 260 ha is controlled (20% in the boreal; 10% in the GLSL) but there is no upper size limit. The upper size limit on the range of clearcut sizes will depend on ecological conditions, fire history, resource values, and decisions by local citizens committees who represent social and economic concerns in each planning area.

- Distance separating cuts will increase with increased cut size. Cuts up to 260 ha will require an average separation of 200 m (minimum 100 m) between adjacent cuts less than 20 years old. Cuts > 260 ha must be separated from similar sized clearcuts by an additional 50 m for every 100 ha increase. For large cuts that require 600 m separation or more, 70% of the buffer must be at least 6 m high. The forest adjacent to the cutover cannot be cut for 20 years or until the regenerating forest in the cut is at least 3 m high.
- The interior of cut areas will require an average of 20% of forest in peninsular intrusions from the uncut buffer into the cutover as well as an average of 5% in clumps of trees within the cutover. In addition, 25 trees/ha must be left standing with 6 being large live trees and 19 others at least 10 cm DBH and 3 m in height. These residual trees should normally be the least combustible in the stand and should be left where they might be expected to remain after a fire.

Conclusion

The process of developing this guide proved difficult because of many uncertainties and

misconceptions. Despite the fact that the guidelines explicitly state that the total amount of forest cut annually would not change, critics equated larger cuts with cutting of more forest area.

Underlying much of the difficulty were uncertainties about to what degree changes in landscape patterns would lead to long-term conservation of biodiversity given that fire is a chemical process and forest harvesting is a mechanical process. This latter difference can lead to differences in species composition and structure within burned areas versus clearcuts. Thus, a criticism of the natural disturbance pattern guide was that emulation of patterns was just an excuse for increasing the amount of cutting rather than curtailing cutting. Another criticism was that there was inadequate science behind the Guide. Many critics wanted to have all uncertainties resolved before the guidelines were implemented. MNR's position was that the uncertainties could not be resolved in the short-term and over the longer-term, the uncertainties can only be resolved with an active adaptive management approach to monitoring the effectiveness of the guidelines and incorporating appropriate changes in future versions.

NOTES

Emulating Natural Forest Disturbances: Silvicultural Concepts and Applications for Silvicultural Systems in Forests in the Northern Great Lakes Region of the United States

John C. Zasada¹, Thomas R. Crow¹, Brian J. Palik¹ and Daniel J. Gilmore²

¹USDA Forest Service, Forestry Sciences Laboratory, Grand Rapids, MN Tel: (218)326-7109; E-mail: jzasada@fs.fed.us

²Department of Forest Resources, University of Minnesota, Grand Rapids, MN

The north temperate and sub-boreal boreal forests of the northern Great Lakes region in the United States have a long history of complex interaction between natural and human disturbance. The presettlement forests were dominated by natural disturbances, but there were also poorly known levels of use and disturbance by Native Americans. The relative importance of the different types of disturbance (e.g., fire, wind, insects, and flooding) varied within and among regions and ecosystems. Climate, geomorphology, and soils determined to a large extent the potential species composition and growth rates of the forest. Forest disturbance, availability of seed, herbivory, and other factors determined the structure, composition, and successional trajectory of a given forest ecosystem at any point in time.

In terms of the present forest condition, settlement of this region, mainly by western Europeans changed the composition and structure of virtually all of this forest. Essentially all of the forestland was cutover. In general, the more valuable pines were harvested first followed by other species in decreasing order of their value. Species whose primary value was not for lumber, for example hemlock for tanning animal skins, were also exploited to a high degree. The iron ore mining operations destroyed forests and large areas were needed to dump the overburden and unused materials. Mining operations also required large amounts of wood. Lands converted to agricultural

use were mostly abandoned and by default returned to forest. These practices and others created ecological conditions for which there was no natural analog. The forests of today exist where these disturbances occurred.

Forest cover returned as a result of natural processes and planned reforestation activities and control of natural disturbance became a top management priority. The degree of effectiveness in controlling natural disturbance varied with the type of disturbance. For example, fire was very effectively controlled, control of flooding along rivers effective to a degree, and control of wind events and insect outbreaks mostly ineffective. In addition to these effects on forests, human activity has introduced new concerns about forest composition, structure and general health – exotic plants, insects, diseases and changes in the composition of the atmosphere are but several examples of changes to the environment that must now be factored into the development of silvicultural systems for forest management.

As we enter the 21st century, the exploration for and evolution of appropriate silvicultural systems to achieve landowner's, manager's, and the general public's goals for forests of this region continues. In addition to the natural and human factors affecting the ecological processes that drive these forests, there is an increasingly important social component. In terms of management of forests, the movement of people into forested areas of the

region and subdivision of land into smaller parcels for home sites and other uses will in many ways define the character of these forests and the options available for developing silvicultural systems to manage disturbance.

Emulating or reintroducing natural disturbance into these ecosystems is a complex issue. There are important ecological and social concerns across the continuum of temporal and spatial scales relative to development of silvicultural systems that deal with planned disturbance. We will concentrate on the stand-level considerations, realizing that larger-scale issues are important and need to be addressed.

In this paper we will discuss the various elements relating to the issue of emulating natural disturbance by presenting examples of development of silvicultural systems to meet objectives of public and private landowners while maintaining the output of the various goods and services from the forest. These examples will include silvicultural systems for the aspen, red pine, and northern hardwood types, establishment/restoration of white pine, and management of riparian zones.

Aspen. The aspen (*Populus* sp.) type is common across the northern Lake States and occurs on a variety of sites. The silvicultural prescription developed over the past 30 years has been clearcutting with little intermediate cultural treatment during a single rotation of 40 to 60 years. In recent years, there has been increasing interest in creating mixed species stands with aspen and other species appropriate to a given site or in converting aspen-dominated sites to species that more closely approach the presettlement forest or species more appropriate for the site than aspen. New silvicultural systems to achieve these goals include 1) aspen reserve tree system that retains aspen and other species in an attempt to reduce aspen suckering and promote establishment of other species through natural or artificial regeneration; and 2) thinning in young stands to open the aspen

canopy and promote the growth of advance conifer and hardwood regeneration.

Red pine. During the past 30-40 years, red pine (*Pinus resinosa* Ait.) has probably been the most intensively managed tree in this region. It produces more volume and a wider variety of wood products on many sites than other species and is relatively free of insect and disease problems. With the availability of herbicides, plantation establishment has been relatively problem free. The silvicultural system developed for red pine consists of plantation establishment, several thinnings to specified basal area levels, pruning (not common at present), and a final harvest at 80-120 years. This system created single species, single cohort stands. More recently there has been an interest in developing alternative silvicultural systems for stands with multiple species and several cohorts. Depending on the site and the landowner's objectives, stands may include white (*Pinus strobus* L.) and jack pine (*Pinus banksiana* Lamb.), balsam fir (*Abies balsamea* (L.) Mill.), various oaks (*Quercus* sp.), and birch (*Betula* sp.) in addition to red pine. Because of the historical importance of underburning in the red pine type, there is interest in using fire to meet selected silvicultural objectives, such as control of hazel (*Corylus* sp.) and other unwanted species in the understory and site preparation for regeneration.

White pine. White pine was a premier species in the presettlement forest. Logging, introduction of blister rust, and insect problems (especially the white pine weevil) greatly reduced the importance of the species. For many years it was more or less ignored by land managers because of the blister rust problem and to a lesser extent the white pine weevil. However, white pine tended to maintain itself on some sites and more recently there has been a renewed interest in managing for white pine. This has been especially true in Minnesota. Over the last 5 years there has been a large effort to re-establish white pine, mainly through planting. The objective has been to have it as a component of mixed stands and not in pure stands.

Northern hardwoods. The intensity of northern hardwood silviculture is second to that of red pine. Silvicultural guidelines for older multiple-cohort stands and second-growth, mostly single-cohort, stands are well established and used extensively in northern Wisconsin and the upper peninsula of Michigan. The guidelines for the second-growth stands can be used for single- or multiple-cohort management. These guidelines have been concerned primarily with production of high value hardwood sawlogs. The maintenance of multiple cohort stands or their development from the second growth stands has tended to increase the presence of the very tolerant sugar maple (*Acer saccharum* Marsh.) and decrease mid-tolerant species such as white ash (*Fraxinus americana* L.), red oak (*Quercus rubra* L.), and basswood (*Tilia* sp.). To increase the presence of the mid-tolerant species, the guidelines have been altered to include creation of gaps of various sizes. These gaps simulate to some degree the occurrence of natural gaps created by wind and provide more resources, mainly light, for establishment and growth of the mid-tolerants. In older stands that have a multiple-cohort structure, the silvicultural systems have been altered

to develop stands that more closely resemble old growth by increasing the maximum tree diameter, leaving cull trees for wildlife habitat, and increasing the amount of coarse woody debris, and creating canopy gaps of various sizes to increase species diversity.

Riparian habitats. Riparian zones and wetland inclusions in other forest types are important habitat for many animal and plant species. These areas have been the target of best management practice guidelines that were mainly concerned with reducing sedimentation and maintaining water quality. More recently, however, interest has increased in developing appropriate silvicultural systems to promote the establishment of longer-lived tree species and increase species and structural diversity. The emphasis to date has been to depend on natural regeneration. However, because of lack of desirable seed sources, it is becoming more evident that planting of desired species needs to be included in silvicultural prescriptions for these sites.

NOTES

Natural Disturbance Patterns and Forest Harvesting in the Western Boreal: From Concept to Practice

Philip Lee, Cheryl Smyth, and Stan Boutin

Department of Biological Sciences, CW-405 Biological Sciences Building, University of Alberta, Edmonton, AB T6G 2E9 Canada Tel: (780)492-5766; E-mail: philipl@ualberta.ca

Landscape patterns following timber harvest are largely driven by the availability of merchantable timber, maintaining a balanced timber inventory, location of transportation corridors, and terrain restrictions. The ensuing pattern has been the best compromise between these, largely economic, factors. Older harvested landscapes are characterized by small aggregations of linearly organized cutblocks dispersed throughout the landbase. Though dispersed cutting is aesthetically appealing, it has a number of ecological consequences. Initially, cutting patterns have relatively little impact. However, the natural landscape becomes more fragmented as harvesting proceeds. In boreal forests, dispersed harvesting accesses pristine areas more quickly and maintains traffic into these areas for a longer time. The potential effects of these activities have caused researchers and managers to explore the potential of aggregating larger groups of cutblocks. Though this pattern has greater initial local effects, it minimizes the extent of impacts across the landscape and long-term risks associated with dispersed cutting. Clearly, what is needed is to explore patterns that decrease the spread of development over the landscape and retain the natural landscape patterns.

In an attempt to maintain a complex, natural pattern over the landscape, managers have begun to explore natural disturbance-succession patterns as a guide for timber harvest. In the boreal forest, this means following a pattern initiated by wildfire and followed by natural succession. Unfortunately, there has arisen an acrimonious argument over whether timber harvest is an appropriate ecological surrogate

for wildfire. It clearly is not. In general, the legacies created immediately after wildfires cannot be mimicked through harvest operations. These differences include high densities of dead trees, burned organic layers, changed soil albedo (reflectance), and different regenerating plant communities in burned areas. Use of a natural disturbance-succession template for timber harvest is an attempt to mitigate the impacts of landscape patterns created by current practices. It is not meant as a replacement for the ecological role for fire.

Current translations of natural patterns to timber harvest landscapes have primarily resulted in larger cutblocks, cutting to natural boundaries, removal of timber in a single pass, and the retention of live tree residual patches within cutblocks. These translations have assumed equivalence between a cutblock and a wildfire. Of these practices, larger cutblocks and the retention of live trees within cutblocks have received the most attention and debate. We believe the use of single cutblock to single wildfire analogy is inappropriate, since the disturbance and subsequent succession created by wildfires occurs over a much larger area than can be implemented within a single cutblock. In Alberta, wildfires less than 1,000 ha are numerically the most common type, however, these only burn about less than 5% of the landbase. Less frequent larger wildfires account for greatest area burned. Even with the current push for larger cutblocks, i.e. ~1,000s ha, it is unlikely that managers will achieve the emulation of large wildfires with individual clearcuts.

To leave behind a more natural landscape and slow the rate of development across the landscape,

we suggest investigating the use of an aggregated harvest pattern that approximates the size and shape of large wildfires. These landscape units would be spaced and scheduled over the entire timber production area so as not to remove too much timber from a single region. Variable amounts of merchantable, residual trees (3-4%) would be left within harvested stands while variable-sized patches (> 5 ha) of merchantable, residual trees (6-7%) would be left over the entire planning unit. Each planning unit would be harvested over a 10-year period, then left for the remainder of the rotation (~70 to 115 years). This is the shortest seral stage, i.e., initiation phase, within boreal forest succession. Over the landscape, these units would produce a patchwork of intensively harvested areas and areas that are relatively unaccessed and undeveloped.

The current natural landscape pattern suggests that there is no "ideal" planning unit size. If planning units follow the size distribution of wildfires then there should be many smaller units and a few larger units. However, larger units will account for most of the area within a total timber management area. The size range of planning units are set by logistic constraints. These include rotation age, total timber management area, annual even-timber flow constraints, road costs (ecological and economic), and the current and future dispersion of merchantable timber over the landscape. In general, larger timber management areas can support larger planning units. As an example, timber management areas with 250,000 ha of productive land may be able to support units varying between 2,500 to 40,000 ha of productive land. In contrast, a management area that has 1,000,000 ha of productive land can support planning units varying from 2,500 to 115,000 ha.

The primary objective with the retention of merchantable trees over a planning unit is to provide a dynamic source of structural complexity for biodiversity. As with planning unit size, the amount of merchantable residuals left after harvest

should reflect that left after wildfire. The material can vary in age but should be separated by at least one seral stage older than the regenerating cohort of trees. Even relatively young material left at harvest will be more structurally complex when the regenerating trees reach maturity. Generally, the amount of live residuals remaining after wildfires is less than 15% of the pre-burn area. However, this is an area of active research and thus the numbers are subject to change.

Residual materials should be left in a range of patch sizes that reflect the pattern after wildfires. Sizes can vary from single trees to patches greater than 80 ha. The most common patch size (by area) ranges from 1 to 5 ha. Based on natural distributions after wildfire, 30-40% of the residuals would be left within cutblocks, while 60-70% (by area) would be left as whole polygons.

Neither in-block nor polygon-sized residuals represent long-term deletions from timber harvest. This distinguishes them from static residual patches such as old growth or riparian management zones. All polygon residual patches can be harvested, but only after most of the landbase has returned to a mature stage, i.e. more than 80 years. This ensures a continued presence of structural complexity within the planning unit. In all likelihood, the harvest of residuals will be largely restricted to polygon-sized elements since extraction of in-block residuals is liable to be uneconomic. These in-block residuals may be harvested when the planning unit is harvested again, i.e., as part of the second rotation.

Many studies strongly demonstrate the benefits of leaving residuals for biodiversity. However, the question remains whether the use of the natural disturbance-succession template performs better for the long-term maintenance of biodiversity than other strategies that also leave residuals. Old growth, riparian zone, targeted species (e.g., ungulates), and endangered species management all leave residuals dispersed over the landscape.

Presumably, species or resources other than those directly targeted will benefit from these residuals. Unlike these residual strategies, the natural disturbance-succession template is not a targeted strategy for maintaining or protecting a particular species or community. It remains untested whether natural disturbance-succession templates provide a basis for a heterogeneous landscape that will benefit a diversity of species. Given the wide range of residual patch types and sizes offered by emulating natural disturbance-succession patterns, it likely that some residuals will overlap with other strategies that require a narrower range of residuals patches. One potential method of integration is to make some changes to the amounts, types, and sizes of residuals to produce a better overlap and integration with other residual strategies such as old growth and riparian management.

In this study, we have attempted to synthesize the available data and develop a top-down approach to landscape planning based on natural landscape created by wildfires. There is dearth of knowledge in understanding and quantifying the similarities/differences in the succession of wildfire and harvest stands. In particular, the early differences between wildfire and harvest, if sufficiently large, overwhelm any advantages of using a structured landscape of residuals to produce significant benefits for biodiversity. On the other hand, greater ranges of patch sizes, natural edge boundaries, and spatially heterogeneous distribution of residuals are likely to benefit biodiversity. However, both are untested hypotheses. The large spatial and long temporal scale for design and implementation suggests long-term experimentation through careful adaptive management and monitoring are appropriate methods of moving these practices forward.

NOTES

Ecological Basis for Emulating Natural Disturbances in Forest Management

Ian D. Thompson

Canadian Forest Service, 1219 Queen St. E., Sault Ste. Marie, ON P6A 2E5 Canada Tel.: (705)949-9461; E-mail:ithompso@nrcan.gc.ca

Introduction

The emulation of natural disturbances has become a paradigm for forest management. Forest management has evolved as a result of continuous research and public interest. A major component of this evolution has been a change in ecological thinking away from theories of ecosystem determinism, equilibrium, and stability, towards a body of theory based on a recognition of the dynamic nature of disturbances in space and time. Natural variability in forest ecosystems has become the model for management. Forest management agencies are embarking on new harvesting strategies that may decrease clearcut size, increase clearcut size, reduce the use of clearcutting and increase the amount of forest retention in harvested areas, increase the use of selection and shelterwood harvesting, and change patch sizes to conform with some ideas or theoretical predictions of natural disturbance patterns.

Changes in management methods and objectives are supported by a widespread recognition of the broad concepts of sustainability and ecosystem management. Under these ideas, the basis for the use of ecosystems is to ensure no loss in goods and services over time, and the protection of biodiversity in time and space. Nevertheless, the literature is replete with multiple definitions for these concepts, illustrating the difficulty in both theory and its application in policy and management. The foundation for emulation of natural disturbances rests in 2 ideas: that disturbance history provides a model for managing ecosystems, and that disturbance as a process is integral to maintaining biological diversity (Landres

et al. 1999). Multi-scaled ecosystem theory argued by Allen and Hoekstra (1992) is relevant to these discussions. The null model is natural disturbances and the alternate is that other forms of disturbance produce different results. The question is then can forest management produce expected (predicted) results by emulating natural disturbances?

Theoretical Basis for Emulating Natural Disturbances in Management

Managing to emulate natural disturbances has its roots in some of the most basic ideas of theoretical ecology. These include theories pertaining to community ecology, evolutionary processes, the functional roles that species play in ecosystems, as well as to the functional relationships among species and between species and ecosystem goods and services. These ideas include concepts at scales from genes to landscapes, including processes that structure communities (e.g., predation, competition, mutualism, and coevolution), niche theory, dispersal, optimal life history and fitness of organisms, maintenance of conditions that enable *normal* natural selection processes, hierarchy theory, and local and regional processes.

Genetic basis

The genetic level is the level of natural selection and evolution. Using ecosystems in an unsustainable manner means that certain selection processes may be altered, resulting in consequent loss of natural genetic variance through directional selection processes, reduced fitness of specialists, and increased fitness of generalists. Inability of species

to disperse reduces gene flow and inability to find mates or to be pollinated results in inbreeding and possible increased hybridization (Ledig 1991). Selective harvest of the best trees may reduce fitness within a population over time, as does post-harvest silviculture that is inattentive to local populations and environmental conditions (Rajora et al. 2000).

Related ideas and concepts:

- maintaining genetic integrity of species (e.g., reduce possible hybridization)
- inbreeding probability (fragmentation, isolation, low population)
- enabling population processes to occur
- maintaining mating systems
- creating abnormal herbivore and predator pressure
- selective harvesting of *best* trees
- supporting natural variability vs. directional selection

Species and community basis

Disturbances affect communities by altering the habitats of species over time and space. The ability of species to recolonize disturbed areas, and successional pathways, are very much a function of the kind and areal extent of disturbances, and whether the new conditions, regardless of their duration, provide optimal habitats. Permanent elimination of habitat, lack of founding populations, inability to disperse, new competitor regimes, and an inability to mate are all potential effects of altered disturbance regimes.

Related ideas and concepts:

- regional and local process effects and the role of history
- dispersal limitation
- community assembly
- altered niche space - generalists, specialists, rare species and habitats
- mortality and productivity
- coevolution and dioecious species
- community convergence and resilience

Ecosystem and forest basis

What do species do in ecosystems and is there a functional relationship between biodiversity and ecosystem goods and services? A driving feature of ecosystems and forests are the *ultimate* limiting variables of climate, soils, and water. History suggests that at least 2 of these variables change at scales relevant to management.

Related ideas and concepts:

- role of biodiversity in ecosystem function and long-term maintenance of system goods and services
- scale of effects in space and time

Landscape basis

At large scales (temporal and spatial) the primacy of large and significant events provide long-term instability to systems. As a result, questions arise about the basis for managing by emulating natural disturbances.

Related ideas and concepts:

- dispersal capability of organisms across altered landscapes
- old forests
- scale of effects in space and time
- process limitation by ultimate factors of climate, soil, water

The Practical Application of Emulating Natural Disturbances

How close can we come and is that close enough? What is the evidence that managers can emulate natural disturbances, and is there a convergence of communities following the two types of disturbances?

Differences between natural disturbance and forest management

The evidence of success in emulation management is at best ambivalent. Studies, particularly of birds, insects, and ground cover plants, suggest that some (or many) species are

lacking from managed ecosystems, even with improved management techniques and that convergence of communities in managed and naturally disturbed forests is lacking and unlikely to occur. On the other hand, at best, forest management is a long-term experiment, and *the experiment* in any forest ecosystem is far from complete since insufficient time has elapsed. Further complicating the issue is that harvesting methods have changed 3 times since 1900 (handsaws and horses, chain saws and skidders, and mechanized harvesting), making drawing firm conclusions from comparison chronosequence studies problematic.

Further, given the importance of stochasticity and history in community assembly, emulating natural disturbances is no guarantee of convergence between communities before and after harvest. Further, predicting future communities based on past conditions ignores the role of history.

Another counter argument? Forestry is benign

An important question is whether differences exist between the effects of forest management and natural disturbances, on the long-term persistence of species. Within continuously forested ecosystems (i.e., within systems that regenerate following timber harvest to new forests and forests are not converted) there is a dearth of evidence that species have been lost, or even that productivity has been lost, at least in boreal and temperate forests. Recent publications criticizing the often-cited widespread loss of biodiversity as a myth (Lomborg 2000, Gibbs 2001) are provocative, demand a clearer marshalling of information (i.e., Pimm et al. 1995), and suggest the need for improved understanding and modelling of species responses to forest management over time.

Conclusions

What can actually be accomplished by managing to emulate natural disturbance, given the highly stochastic nature of disturbances and the primacy of climate in controlling disturbance patterns at long temporal scales? Or should we simply manage to maintain a certain specified and publicly acceptable biodiversity?

There has been considerable debate over the ability of forest managers to emulate natural disturbances. Further, it is an untenable argument to suggest that we can emulate natural disturbances when so many of these processes differ so dramatically in their type (chemical vs. physical), result (biomass removal, nutrient leaching), and effects on landscape pattern. Does this therefore mean that the paradigm is invalid? The answer is a question of degree. The object of disturbance emulation is not to make a clearcut look like a fire, but rather to recognize and understand the differences between management and natural disturbance, and to use that knowledge to improve harvest methods so as to impair ecosystems and their processes as little as possible.

References

- Allen, T.F.H. and T.W. Hoekstra. 1992. *Toward a Unified Ecology*. Columbia Univ. Press, New York, NY.
- Gibbs, W.W. 2001. *Sci. Am.* 285: 40-49.
- Ledig, F.T. 1992. *Oikos* 63: 87-108.
- Lomborg, B. 2001. *The Sceptical Environmentalist*. Cambridge Univ. Press, Cambridge, UK.
- Landres, P.B. et al. 1999. *Ecol. Applic.* 9: 1179-1188.
- Pimm, S.L. et al. 1995. *Science* 269: 347-350.
- Rajara, O.P. et al. 2000. *Molec. Ecol.* 9: 339-348.

NOTES

A Conservation Biologist's Perspective on Emulating Natural Disturbance Management of Boreal Forests

David L. Euler¹, Chris Henschel², and Tom Clark³

¹Birch Point Enterprises, Box 6, Site 4, R.R. #4, Echo Bay, ON, P0S 1C0 Canada Tel.:(705)248-1494; E-mail: birchpt@sympatico

²Wildlands League, 401 Richmond Street, W, Suite 380, Toronto, ON, M5V 3A8 Canada

³CMC Ecological Consulting, RR #1, 1150 Golden Beach Road, Bracebridge, ON, P1L 1W8 Canada

The Conservation Biology Perspective

The Society for Conservation Biology, formed in 1985, is an ... *international professional organization dedicated to promoting the scientific study of the phenomena that affect the maintenance, loss, and restoration of biological diversity*. Members and adherents strive to understand changes in biological diversity that occur as a result of human activities, as well as normal evolutionary changes, and study the effect of these changes on ecosystem diversity. A major purpose of the Society is to deliver sound scientific advice to policymakers and natural resource managers. In general, the goal and objectives of conservation biology focus on conserving the biodiversity of ecosystems. The purpose of this paper is to view the process of emulating natural disturbance in forest management through the lens of conservation biology.

What do Conservation Biologists Want?

Like other disciplines, conservation biologists do not have a universal approach to forest management that is accepted by all. Conservation of biodiversity, however, is a concept that virtually all can agree on. The problem with the biodiversity concept is that it is broad, and means different things to different people. The concept suffers from a lack of detail of exactly how a manager would approach forest management to conserve biodiversity and achieve ecological sustainability.

Many conservation biologists believe that there are several critical characteristics to be carefully considered, as a minimum, in decisions about forest management to make the vague concept of biodiversity more practical. These include:

- The size of clear-cuts
- The amount of old-growth forests on the landscape
- The wildlife species that are vulnerable to depletion as a result of timber harvest
- The age class distribution of major tree species
- The changes in ecosystem diversity, particularly plant species diversity
- The pattern of plant communities at the landscape level
- The existence of populations of vulnerable, threatened, and endangered species

An approach to forest management, based on the concept of emulating natural disturbances, needs to consider these critical characteristics and try to emulate them in a management process. If managers could successfully manage a forest that mimicked natural processes in these critical characteristics that would be considered successful.

Conservations Biologists Are Realistic

One of the universal facts of ecology is that many forested ecosystems are always in a state of

flux. As a result of these normal changes in ecosystems, a single, clear target for each critical characteristic described above is not available for every area. The amount or percentage of old-growth in an unharvested forest will not always be the same in every area, age class distributions are never in stasis, and diversity ebbs and flows in response to many kinds of events such as fire, wind storms, insect defoliation, parasitic organisms, human influences, and probably others as well. It is a mistake to believe that anyone can manage a forest to keep a given characteristic at a specified level for long periods of time, or maintain rare species if evolutionary forces are pushing them to extinction.

What is Wrong With Past Forest Management?

The problem with most forest management, in North America at least, is that for much of the 20th century, managers did not use critical characteristics of the unharvested forest as a guide to harvesting practices. For many years, foresters were taught to manage for a *normal* forest in which commercial tree species were equally distributed across a small number of age classes. Plant species diversity was often deliberately reduced to channel more primary productivity into commercially valuable tree species. Progressive clearcuts were common and removed even-aged stands of species like jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) without much thought to the impact of these cuts on the diversity of animal and plant life in the area. Game species were often favoured over small furry or feathered animals and thinking about the pattern of plant communities on the landscape was not a priority.

Emulating natural disturbances in forest management is attractive to conservation biologists as a method to try to conserve biodiversity, at something close to the diversity of an unharvested forest. This is both an ethical and philosophical position, as well as a practical one. First, it seems like the right thing to do (Hunter 1993) and second,

the best hedge against an uncertain future is to, in Aldo Leopold's (1949) words, ...*keep all the pieces*. Evolutionary, climatic, and biogeochemical events will make many changes to forested ecosystems, but people should try to let those events occur, while humans use what is needed, but attempt to keep human management within limits imposed by non-human events.

How Would the Conservation Biology Approach Change Forest Management?

A conservation biologist would strive to maintain critical characteristics of the forest and the forested landscape, within the change regimes that have occurred in the past. Yves Bergeron and colleagues (e.g., Harvey *et al.* 2002, Gauthier this volume) illustrate how to conduct logging operations that maintain an age structure that is consistent with the age structure of unharvested forests. Schroeder and Perera (2001) and Boychuk *et al.* (1997) provide considerable background information useful to forest managers concerning vegetation patterns and the impact of fire and logging disturbances at the landscape level.

Burton *et al.* (1999) show how forests can be harvested for economic benefit and still conserve old growth forests. Andison (1998) illustrates how a computer model can be used to simulate the effects of forest harvesting and compare those results to a landscape that evolved without timber harvest. Baker (1993) provides a method of restoring a landscape changed by fire suppression to a landscape more like a natural disturbance regime. Seymour *et al.* (2002) recently described an index that has the potential to measure the sum of forest management activities against a standard that might be termed *natural variation*. Askins (2000) and Imbeau (2000) provide guidance with regard to wildlife and forest management, and consider wildlife species vulnerable to timber harvest and suggest ways of dealing with that issue.

Conservation biologists can support the idea of emulating natural disturbance in forest management as long as all the critical characteristics are considered. The broad goal would be to keep the changes imposed by forest managers within the limits imposed by change elements that often occur in forest ecosystems. Ontario's recent commitment to implementing a *Forest Management Guide for Natural Disturbance Pattern Emulation* is laudable; however, the emphasis in that guide is primarily on the size of clearcuts. To be supported by the conservation biology community, policy should address all the critical characteristics of the forest. Tools are available to accomplish this goal and, if they are used properly, the goal of ecological sustainability can be attained, biodiversity can be conserved, and economic benefits will be available for people over the long term.

References

- Andison, D.W. 1999. *Ecography* 21: 543-550.
- Askins, R.A. 2000. *Restoring North American Birds*. Yale Univ. Press, New Haven, CT.
- Baker, W.L. 1993. *Conserv. Biol.* 8:763-769.
- Boychuk et al. 1997. *Ecol. Model.* 95:145-164.
- Burton, P.J. et al. 1999. *For. Chron.* 75:623-631.
- Harvey et al. 2002. *For. Ecol. Manage.* 155:369-385.
- Hunter, M.L., Jr. 1993. *Biol. Conserv.* 65:115-120.
- Imbeau, L. et al. 2000. *Conserv. Biol.* 15: 1151-1162.
- Leopold, A. 1949. *A Sand County Almanac*. Oxford Univ. Press, New York, NY.
- Seymour, R.S. et al. 2002. *For. Ecol. Manage.* 155: 357-367.
- Schroeder, D.J. and A.H. Perera. 2002. *For. Ecol. Manage.* 159: 217-230.

NOTES

What Are the Economics of Emulation Forestry?

Daniel McKenney¹, Al Mussell², Glenn Fox³

¹ Canadian Forest Service, 1219 Queen Street East, Sault Ste. Marie, ON, P6A 5M7 Canada
Tel.: (705) 949-9461 x2316; E-mail: dmckenne@nrcan.gc.ca

² George Morris Centre, Guelph, ON

³ University of Guelph, Guelph, ON

Introduction

Emulation silviculture attempts to apply management techniques that imitate natural disturbance processes. The aim is to somehow minimize the environmental effects of forest harvesting. In fact, there is considerable controversy over the effectiveness of such approaches. Notwithstanding these debates there are also economic implications to natural disturbance forestry. This paper presents the theoretical basis for economic analysis of these issues. We also present a case study of the woodland caribou/wood supply forest management problem in northwestern Ontario. This is an exemplary example of the challenges of implementing and analyzing emulation forestry. To maintain the species in the region wildlife managers believe innovative approaches to forest management are required. These policy suggestions will particularly affect the spatial pattern and timing of timber harvests over a very large geographic region. The intent is to emulate large-scale fires, which will affect habitat quality in the region and hopefully increase the long-term viability of the caribou population.

Some Forest Economics Concepts

Interestingly the economic calculus involved is same whether one is evaluating intensive, extensive, conventional, or emulation silviculture. In a world where only wood is valued, the economic problem is to determine what age to harvest a stand of trees to maximize its value through time.

This is the so-called Faustmann model and data are usually constructed/developed for representative hectares in the region of interest. Although the original Faustmann model was created to apply to

bare land, it identifies the key elements of the wood production problem – these are timber volumes through time, establishment costs, standing timber values, and the cost of time, a discount rate. The rotation length chosen from all possible prescriptions is the one that maximizes the net discounted value of wood production over an infinite number of rotation periods. This is the optimal economic rotation length. No other rotation will provide as great a return. An intuitive interpretation is that the timber should remain uncut until the rate of growth of the asset, which includes the wood and the land, equals the real discount rate, where the discount rate represents rates of return from other investments in the economy. The optimal rotation period is dependent on the stumpage price, the discount rate, and management costs when costs are positive. From a wood production perspective the notion of a representative hectare is logical and defensible insofar as prices are independent of harvest levels.

An alternative to the Faustmann model, referred to as the Hartman model, has been proposed in which the standing forest has value. It is based on the important fact that standing timber values vary spatially, affecting the economic calculus of forest management plans over large geographic areas. This is the case in our caribou example and may be the case in other emulation of natural disturbance management problems. It is common to use linear programming for large forest management problems with many timber stands; however, this is not as well suited to our case study. Simulated annealing is a stochastic optimization technique that is better suited to large combinatorial problems and is the approach we use in this analysis.

The Woodland Caribou Management Problem in Northwestern Ontario

Woodland caribou are a large, nomadic deer species native to northern Canada and Alaska. In northwestern Ontario, woodland caribou are relatively rare. Only 2,000 to 5,000 animals are thought to exist over an approximately 7,000,000-hectare area. The region includes 17 administrative Forest Management Unit areas. Over the past century, the range of woodland caribou in Ontario has been receding northward. This roughly corresponds with the northerly boundary of current commercial logging operations. In recognition of the decline in woodland caribou numbers, the Ontario Ministry of Natural Resources (OMNR), the primary land manager in Ontario, has initiated a new management strategy through its Wildlife Policy Branch. Identified goals include maintaining current population levels and habitat, providing Aboriginal and possible future sport harvest opportunities, and ensuring public viewing opportunities.

Timber management operations are recommended to form a long-term habitat mosaic with large areas of specific tree species, age classes, and stocking rates. The mosaic should consist of harvest blocks of at least 100 km² scattered throughout large areas of the caribou's range and thus provide sufficient winter habitat for caribou over time. The larger cutovers are intended to simulate the effect of fire, a natural disturbance regime and, historically, the primary driver of habitat renewal in boreal forests in the region. Adjacent blocks could not be harvested for 20 or more years. One concern of industry is that large tracts of merchantable timber may have to be bypassed to harvest in more remote and perhaps less desirable areas. This may increase road construction and maintenance costs and bypassed stands may later be lost to fire, disease, or blowdown. Ironically perhaps, individual clearcuts under the proposed guidelines would be much larger than current practices.

Summary and Concluding Comments

Caribou habitat management in northwestern Ontario is a distinctive problem but representative of the need to practice emulation forestry. Habitat management requires a broad geographic perspective – much larger than traditionally considered in forest management. There are numerous trade-offs and the issue is contentious in the region. From an economic perspective, it is difficult to estimate the benefits of caribou preservation. Caribou are not allocated for harvest as are hunted species and, as such, no form of market exists to provide insights on what people would be willing to pay to preserve the population for hunting opportunities. Caribou are of some value as a subsistence food for natives in northern Ontario and may possess an existence and/or ecosystem function value; however, deriving such values for use in environmentally adjusted cost-benefit analysis would be difficult and fraught with uncertainty. Our approach was to estimate an opportunity cost of habitat management in terms of the potential timber forgone due to implementing a caribou habitat management policy.

Our analysis was spatially explicit. The topology of over 600 100-km² forest patches (location relative to other units) was derived and standing timber values were adjusted based on likely transportation costs. Several scenarios of implementing and not implementing the caribou guidelines were analyzed. There are clear costs of the caribou guidelines on wood supply. The estimated opportunity costs ranged from 129.6 to 295.1 million (\$Can) (\$0.74 to \$1.17 per Ontario resident).

In some respects the analysis is very much an academic exercise. Adoption of a harvesting strategy as suggested by the results would signify a remarkable shift in forest management. Harvesting operations and wood supply modelling are not

generally coordinated over such large areas. Transaction costs not accounted for in this analysis may occur if the caribou guidelines were implemented in this manner. Currently planners in the region are attempting to implement the caribou

guidelines within each forest management unit independently. This presents other types of operational challenges. Ultimately economic assessments of emulation silviculture will require a combination of spatial and non-spatial analyses.

NOTES

Expectations and Consequences of Emulating Natural Forest Disturbance: A Forest Utilization Perspective

Darryl Hebert

Encompass Strategic Resources, RR #2 599 Hwy 21, S., Creston, BC, V0B 1G2 Canada Tel.: (250)428-3092

Introduction

Forest management in Canada has relied on sustained yield management for decades. In short, sustained yield management is the art and science of maintaining the optimum or maximum flow of fibre to the mill. It uses improved silvicultural technology to sustain the income of forest workers and a large part of the Canadian economy. Generally, forest harvesting contributes between \$20 and \$30 billion to Canada's net balance of trade, annually. Most of this income originates from the sale of products into foreign markets, while supporting our standard of living and social services, including health and community development. Strong economic growth, using sustained yield, supports the employment of over 837,000 workers across Canada.

Canadian forests contain approximately 234.53 million hectares of commercial timber – all in productive area, although it continues to decline slightly each year. Of the total commercial forest, currently approximately 0.4% is harvested annually, while the area depleted by fire and insects is about 0.5%.

Emulating Natural Disturbance

Sustained yield forest management allowed little opportunity to protect and maintain non-timber values such as wildlife, biodiversity, and basic ecological processes. The struggle to balance economic growth and non-timber values was most often adversarial, leading to removal of the forest landbase for protected areas, reduction in annual allowable harvest, and increased cost. Dr. C. Binkley at the University of B.C. suggests that a 10% harvest reduction in 1989 in B.C. produced an

employment reduction of 2.2% or 31,570 people, and a 2.5% or \$1.9 billion decrease to the provincial GDP.

The move to protect non-timber values by changing forest management practices became known as sustainable forest management (SFM). At about the same time, researchers introduced the concept that emulating natural forest disturbance (ENFD) and ecological process and structure could lead to SFM.

So, what is the role and potential effect of emulating natural forest disturbance on traditional forest management? In general, ENFD tends to reduce the annual harvest and can often reduce it significantly at a regional or local level. It tends to protect mature and overmature forests that are planned for current and future harvests. Although the Canadian harvest rate may be only 0.4%, while natural disturbance levels are about 0.5%, local harvest levels may be 0.5% to 1% depending on the province, the company, and the length of time the company has been harvesting. ENFD also means leaving areas completely undisturbed, as protected areas, similar to fire skips in a natural disturbance system.

Fires usually occur randomly on the landscape, burning a variety of young and old age classes, while producing highly variable shapes and sizes. In order to reduce costs, harvesting targets mature timber and has restricted the shape and often the size of openings for practical reasons. Currently, harvesting and fires are usually additive in their effect on fibre availability. For ENFD to be effective, natural disturbance management must reduce and compensate for disturbance/forest

health issues.

At a stand level, fires create dead standing timber (snags) while harvesting removes the stems. To emulate natural disturbance, harvesting must address the issue of leaving snags, or maintaining green trees at 3 to 15% retention, as wildlife trees and as a base for future snag production. Similarly, high utilization practices and policies must be adjusted to accommodate requirements for coarse woody material. As such, fibre flow is reduced, costs increase, and economic return becomes restricted. Severe fires often produce delayed successional development, maintaining early shrub stages for long periods. Sustained yield attempts to regenerate harvested stands as quickly as possible, reducing early seral shrub development. Regeneration delays to promote seral shrubs has a significant cost in delayed or lost timber volume. In

general, fires do not maintain linear buffer strips along streams. Forests along streams are burned periodically, in a dynamic fashion. Protection of buffer strips does not necessarily follow the ENFD concept, but can tie up 4 to 7% of the timber volume.

Conclusions

Almost every aspect of ENFD, at a forest, landscape, and stand level, reduces the annual allowable harvest and reduces economic return. When questions are asked individually, public answers support maintaining or improving their standard of living, while at the same time enjoying a healthy environment. As ENFD develops and is implemented, these questions must be asked together to assess tradeoffs and options. There is no free lunch.

NOTES



CASE STUDIES

Presettlement Forest Cover in Northeastern Ontario

Fred Pinto and Stephen M. Romaniuk

Forest Research and Development, Ontario Ministry of Natural Resources, 3301 Trout Lake Road, North Bay, ON, P1A 4L7 Canada Tel.: (705)475-5563; E-mail: fred.pinto@mnr.gov.on.ca

Introduction

Knowledge of the presettlement forest condition is becoming an important component of forest management plans in Ontario. Though the history of many forests in the Great Lake States have been reconstructed, very little work has been done in Ontario. Changes in forest cover over the past 50 to 150 years can be shown when comparing the land survey information to current Forest Resource Inventory (FRI) data, and may provide insight into future changes and their determining factors (e.g., logging, climate). Forest reconstruction has never been attempted over such a large area (Figure 1); analysis and validation of the land survey method will help to realize the use of this uncommonly complete historic data in forest management planning in Ontario. The main objective of our study is to illustrate changes in forest composition and to speculate as to the dominant driving forces and their implications in controlling vegetation change.

Methods

Presettlement forest composition was reconstructed from Ontario Crown Land Survey Notes (OLS) dating from 1856 to 1958 in central and northeastern Ontario (Figure 1). The survey notes contain a detailed description of vegetation cover along the boundaries of each township including the name of the township, the location and extent of the stand along the township boundaries, and a list of tree taxa present within the stand. Stands were delineated by changes in taxa composition or changes in the order in which taxa were listed.

Only the dominant or first listed species was used here to summarize forest cover in the OLS and FRI. Future analyses will include descriptions of all species mentioned. The survey notes explain only the forest composition along township boundaries and do not explain entire forest cover as the air-photo based FRI do. To account for this discrepancy and perhaps validate the land survey method, the FRI will be transcribed into township boundaries and compared to the entire cover to determine the accuracy of boundary descriptions in recreating the entire forest. This has not yet been completed.

In the analysis of tree functional categories, dominant species were grouped into hardwoods and conifers and their percent forest cover calculated. The mid-tolerant and tolerant hardwoods could not

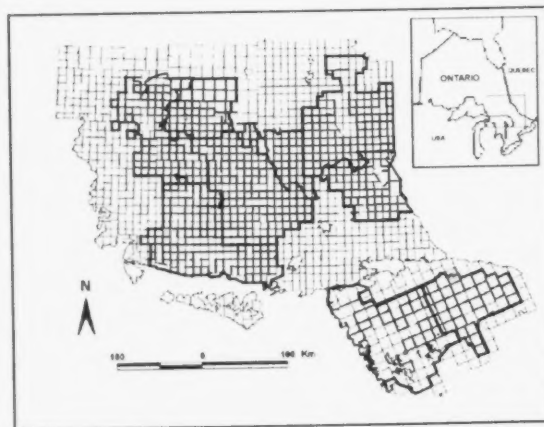


Figure 1. Current study area, which includes 9 Forest Management Units (FMUs) in northeastern and central Ontario. Bolded areas represent the township boundaries where Crown Land Survey Data have been obtained.

be distinguished from intolerant hardwoods since birch species were not always distinguished in all land surveys. Since some surveyors documented individual species, each of the surveyor's records will have to be analyzed individually to determine changes in individual species.

Results and Discussion

Some major trends are visible in the comparisons (Table 1), namely increases in hardwoods (birch, poplar and maple) and decreases in softwood conifer species, especially pine, jack pine and spruce. These changes are further illustrated using tree functional categories (Figure 2), which also show a decrease in conifers and an increase in hardwoods in all FMUs in the study area. Similar results have been found in other studies (Jackson et al. 2000). Cwynar (1977) and Radeloff et al. (1999), among others, attribute changes to a combination of logging and fire. In the past, for example, logging slash left behind often caused subsequent fires that destroyed potential regeneration, further damaged or killed seed trees and at times burned off the mineral soil. In the southcentral FMUs, Parry Sound and Algonquin Park, some other trends are evident. There are noticeable declines in cedar, beech, birch, and larch, in contrast, red and

white pine remained abundant. The lack of change in the latter however, may be a result of the fact that much of the Algonquin Park and Parry Sound FMUs had already been logged before the time of the original land survey.

The comparability of the FRI with the land surveys can be questioned. At this point we cannot confidently say that township boundary coverage is indicative of the entire forest. We will be able to confirm their accuracy once the validation has been completed (as described in the methods). It has also been suggested that land survey information may be inherently different from FRI data since the latter is air based and may underrepresent closed conifer understory species, such as eastern white cedar and balsam fir (i.e., balsam fir decreased in all FMUs in the study area; Table 1).

There is evidence that cooler and moister conditions brought on by the Little Ice Age (1350-1850) resulted in species changes such as an increase in northern hardwoods and a decrease in dry tolerant or fire-dependent conifers. Changes due to past influences can give insight into species tolerance toward changing global climate. Species changes due to climate as well as other factors like disease, insect outbreaks, and natural disturbance can confound changes relating to human influences including forestry and agricultural clearing.

Table 1. Comparison of percent composition of first tree taxa listed in the Ontario land survey notes (OLS; 1856-1958) and FRI (1992-2001).

Species	Superior Forest		Temagami Forest		Spanish Forest		Temiskaming		Shiningtree		Pineand Martel		Northshore Forest		Parry Sound		Algonquin Park	
	Surveys*	FRI**	Surveys	FRI	Surveys	FRI	Surveys	FRI	Surveys	FRI	Surveys	FRI	Surveys	FRI	Surveys	FRI	Surveys	FRI
ash	0.19	0.01	0.14	0.06	1.49	0.00	0.03	0.04	0.17	0.00	0.17	0.03	0.36	0.19	0.86	0.53	0.50	0.09
basswood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.03
beech	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	2.61	0.36	2.00	0.28
balsam fir	3.90	0.91	6.02	1.90	4.61	0.31	6.57	1.28	3.71	1.56	3.51	1.41	3.19	1.79	7.56	6.24	6.07	5.32
birch	14.86	29.08	12.19	26.70	14.80	21.80	9.87	14.64	5.75	24.51	12.41	18.09	12.88	19.11	12.94	4.44	17.37	8.95
eastern white cedar	1.89	3.35	5.42	8.11	1.90	0.73	2.28	1.01	1.93	2.65	4.18	8.84	3.40	2.03	4.55	0.87	4.11	0.81
cherry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.09	0.14	0.00
white elm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.04	0.00
hardwood***	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.99	8.41	0.02	0.02	8.25	0.00
hemlock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	0.93	12.63	4.34	3.70	6.55
ironwood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
larch	0.61	0.69	1.63	0.05	2.11	0.23	7.06	1.22	1.04	0.43	2.16	0.97	2.19	0.25	4.54	0.44	3.54	0.03
maple	0.48	1.05	0.40	4.44	0.24	1.15	0.06	0.73	0.23	2.37	0.09	0.07	8.02	14.19	25.94	49.48	17.37	41.69
oak	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	1.91	0.00	4.63	0.13	2.57
pine (red or white)	3.63	0.57	14.14	11.45	7.23	5.13	1.44	0.41	8.11	0.32	2.56	0.29	27.61	12.97	12.42	11.38	14.33	14.55
jack pine	26.91	20.57	12.42	10.32	31.75	28.05	23.74	22.52	41.03	26.61	27.54	14.25	16.33	19.10	1.51	2.85	1.72	0.59
poplar	9.76	19.08	10.41	16.88	9.17	18.55	9.64	30.20	3.53	16.49	12.81	23.49	5.43	21.78	0.73	11.32	16.37	14.22
spruce	8.75	4.65	29.41	20.80	22.89	13.85	15.56	17.96	36.73	17.51	32.55	12.45	17.17	6.35	4.42	1.89	3.63	4.12

*Percent of boundary length using following species in each stand

**Percent of boundary length using following species in each stand

***Percent of boundary length using following species

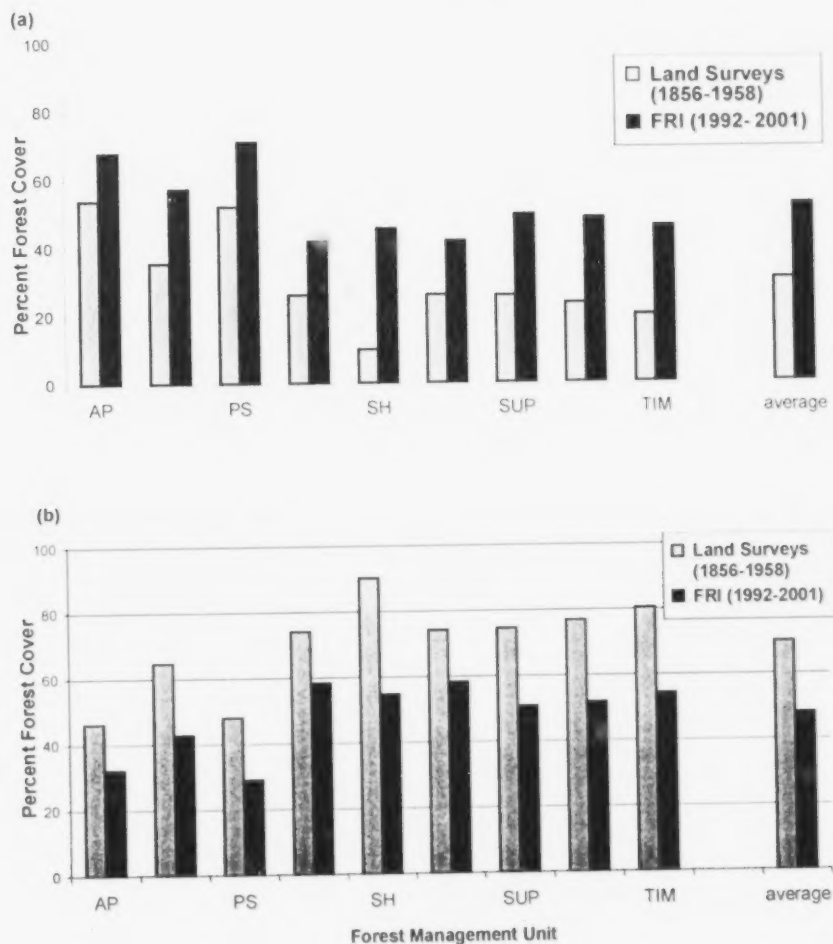


Figure 2. Percent forest cover of dominant species in 9 FMUs including: AP, Algonquin Park, NSF, Northshore Forest, PS, Parry Sound, PM, Pineland Martel Forest, SH, Shiningtree Forest, SUP, Superior Forest, TEM, Temagami Forest, TIM, Timiskaming Forest. (a) tolerant, mid-tolerant (oak, maple, beech, elm, other hardwoods) and intolerant hardwood (cherry, poplar, ash) dominated stands, and (b) conifer-dominated stands (balsam fir, eastern white cedar, pine, hemlock, tamarack and spruce). Birch species were not distinguished, thus all hardwoods were grouped as one.

References

- Cwynar, L.C. 1977. *Can. J. Bot.* 55: 1524-1538.
- Jackson, S.M. 2000. *Can. J. For. Res.* 30: 605-612.
- Radeloff, V.C. 1999. *Can. J. For. Res.* 29: 1649-1659.

NOTES

Using Natural Fire Regime-Based Criteria to Evaluate Forest Management in the Oregon Coast Range, USA

Michael C. Wimberly¹, Thomas A. Spies² and Etsuko Nonana³

¹University of Georgia, Warnell School of Forest Resource, Athens, GA, USA 30602, Tel.: (706)583-8097; Email: wimberly@forestry.uga.edu

²USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331

³Department of Forest Science, Oregon State University, Corvallis, OR 97331

Introduction

Forest management policies in the Oregon Coast Range have diverged into 2 distinctive tracks. On privately owned forestlands, the predominant management approach is clearcutting at relatively short rotations (< 50 years). Under the Northwest Forest Plan, most of the federal landbase is set aside as late-successional or riparian reserves in which timber harvest is restricted. Landscape-level management based on pre-settlement disturbances has been proposed as an alternative approach that could maintain wood output while sustaining populations of native species and essential ecosystem processes. In this system timber harvests would be patterned in time and space to emulate the historical fire regime. Because native species persisted in the dynamic pre-settlement landscape, they should also survive in a managed landscape with similar structure and dynamics.

The goal of this study was to reexamine current forest management practices and landscape patterns in the context of the natural fire regime. Specific objectives were to 1) contrast the frequency, sizes, and effects of historical fires with forest management disturbances, 2) examine differences in the abundance and pattern of seral stages between pre-settlement and present-day forest landscapes, and 3) assess the potential for applying fire regime-based management in the Oregon Coast Range.

Materials and Methods

Data on pre-settlement fire regimes was derived from published studies based on paleoecological

(Long et al. 1998), dendroecological (Impara 1997), and historical (Teensma et al. 1991) research. These fire regimes were contrasted with timber harvest disturbances measured in a remote-sensing study of landscape change from 1972 to 1995 (Cohen et al. in press). Pre-settlement landscape dynamics were simulated using the Landscape Age-Class Dynamics Simulator (LADS), a spatial simulation model that predicted fire initiation, spread, and effects using fire regime data. Historical landscape simulations were contrasted with a remote sensing map of present-day vegetation patterns (Ohmann and Gregory in press).

Results and Discussion

Fire return intervals at Little Lake, in the Central Coast Range, varied from 189 to 220 years over the 1000 years prior to Euro-American settlement (Long et al. 1998). Natural fire rotation in the Central Coast Range was estimated at 452 years for the 400 years prior to settlement (Impara 1997). The fire rotation shortened to 78 years during the settlement period from 1850 to 1910 because of warming climate and increased ignitions by settlers. The fire rotation increased again after 1910 as fire suppression became more effective. A significant proportion of the area disturbed by fire burned at moderate severity, leaving cohorts of live remnant trees (Impara 1997). Even predominantly stand-replacing burns often left some trees as scattered individuals or in small patches. Mean fire size from 1850 to 1940, computed using maps from Teensma et al. (1991), was 8200 ha. The fire size distribution was highly skewed with many small fires, but 71%

of the total burned area was affected by fires larger than 50000 ha. Spatial variability in fire regimes was primarily related to climate; moist coastal forests had longer fire return intervals, larger fire sizes, and higher fire severities than the drier inland forests.

Twenty-one percent of the Coast Range was clearcut between 1972 and 1995, equivalent to a harvest rotation of 108 years (Cohen et al. in press).

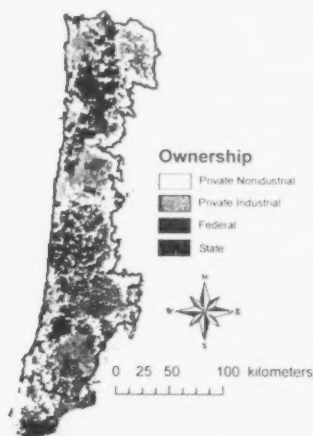


Figure 1: Forest ownership patterns in the Oregon Coast Range. Dark line represents the extent of the LADS simulations.

Fires burned only 0.05% of the Coast Range over the same period. In contrast to fires, most present-day timber harvests retain few live trees within their boundaries (Hansen et al. 1991). The mean size of aggregate harvest units was less than 200 ha, with no units larger than 5000 ha. Spatial variability in rates and sizes of timber harvests is controlled by the management regimes on different forest ownerships (Figure 1).

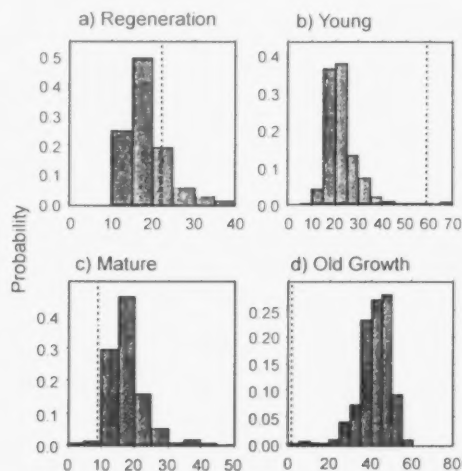


Figure 2: Simulated historical range of variability for the abundance of forest seral stages. Dashed lines represent the current landscape.

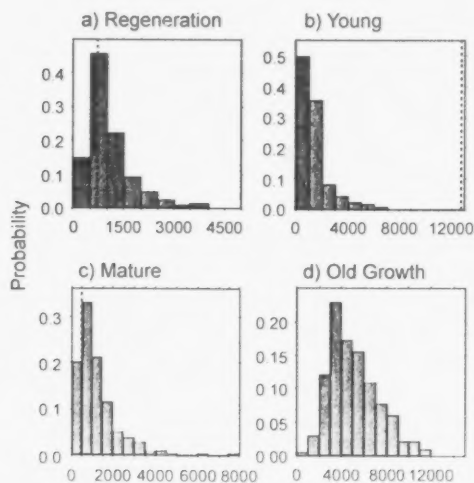


Figure 3: Simulated historical range of variability for the largest sized patch of each seral stage. Dashed lines represent the current landscape.

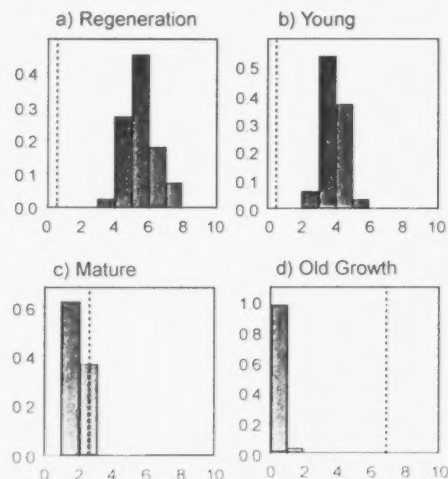


Figure 4: Simulated historical range of variability for the isolation index of each seral stage. Dashed lines represent the current landscape.

LADS simulations demonstrated that the concepts of disturbance regime and landscape dynamics are scale-dependent. The range of pre-settlement landscape variability must be studied over relatively large areas (> 100,000 ha) and long time intervals (< 500 years) because the occurrence of large fires makes landscape dynamics unstable at smaller scales (Wimberly et al. 2000). For the entire Coast Range (> 2 million ha) the percentage of mature and old-growth forest (> 80 years) is smaller, and the percentage of young forest (30-80 years) is greater than expected under the presettlement fire regime (Figure 2). Historically there was at least one large (> 200,000 ha) patch of old forest on the landscape at all times, but the largest old growth patch in the current landscape is only 500 ha in size (Figure 3). Finally, whereas young and old forests were historically in close proximity, a decrease in the total number of old growth patches has isolated much of the present-day landscape from old forests (Figure 4).

Current forest management practices in the Coast Range could be altered to better emulate pre-settlement disturbance regimes. Timber harvests could be spatially clustered to generate large disturbance patches similar to fires and leave large blocks of undisturbed forest. To bring old growth up to historical levels, however, harvest rotations would need to be lengthened considerably.

Alternatively, more live trees, snags, and logs could be retained after cutting to emulate the effects of moderate-severity fires. However, it may still be decades before many young forests begin to develop old growth structure. Thinning can increase tree growth and structural complexity in young stands and may speed the rate of old growth structure development. Perhaps the greatest challenge is the complex pattern of forest ownerships, each with very different management goals, regulatory constraints, and harvest regimes (Figure 1). Any future natural-disturbance based forest management policy in the Coast Range will necessarily represent a compromise between our scientific understanding of disturbance and its ecological effects, and the economic, social, and political realities of the region.

References

- Cohen, W. B. et al. In press. Ecosystems
- Hansel et al. 1991. *Bioscience* 41: 382-392.
- Impara, P. C. 1997. Ph.D. thesis, Oregon State University.
- Long, C. J. et al. 1998. *Can. J. For. Res.* 28: 774-787.
- Ohmann, J. L. and M. J. Gregory. In press. *Can. J. For. Res.*
- Teensma et al. 1991. BLM Tech. Note T/N OR-9.
- Wimberly et al. 2000. *Conserv. Bio.* 14: 167-180.

NOTES

Using Insect-Caused Disturbance Patterns in Northern New Brunswick to Inform Forest Management

Kevin B. Porter¹, Brendan Hemens^{2,3} and David A. MacLean³

¹Natural Resources Canada, Canadian Forest Service, P.O. Box 4000, Fredericton, NB, Canada E3B 7G8
Phone: (506)452-3838 Fax: (506)452-3525 Email: kporter@nrcan.gc.ca

²BioForest Technologies Inc.

³Faculty of Forestry and Environmental Management, University of New Brunswick

Introduction

Black Brook District in northern New Brunswick represents some of the most intensively managed forestland in Canada. Outbreaks of eastern spruce budworm (*Choristoneura fumiferana* Clem.) and to a lesser extent, forest fires and windthrow events, are the dominant natural disturbances in this region in the absence of suppression and control. The Spruce Budworm Decision Support System (SBWDSS – MacLean et al. 2001) was used to model the forest changes caused by defoliation during budworm outbreaks, and to facilitate incorporation of insect damage into forest management planning. The SBWDSS was used to analyze patterns of budworm outbreaks and to determine effects on the Black Brook forest. We describe the adaptation of the SBWDSS to simulate temporal and spatial landscape development using budworm disturbance scenarios based on historical defoliation records, and discuss how the results of such simulations can be used to set forest management objectives.

Methods

Fifty years of aerial defoliation survey maps were digitized and analyzed to characterize past disturbances and to provide a spatial chronology of outbreaks as input to the models. Aerial photographs from 1946 were interpreted, digitized, and analyzed to provide a reference forest condition. GIS-based forest inventories from the early 1980s and mid-1990s were utilized to provide temporal snapshots of the forest condition. A

database containing 25,000 forest inventory sample plots was analyzed to quantify stand structure changes over time using a defoliation-sensitive stand simulation model. The inventory databases were used as input to SBWDSS to project forest state forward using a range of natural disturbance (spruce budworm outbreaks) and harvesting scenarios. The distribution of vegetation types and structures resulting from the natural disturbance scenario was used to define guidelines for stand- and forest-level treatments that are consistent with natural stand structures and disturbances.

Results and Discussion

Analysis of the historic spruce budworm outbreak patterns revealed extensive defoliation in the 190,000 ha Black Brook district during the past half-century. Figure 1 shows two distinctive outbreaks beginning about 1950 and 1973. Over one-half of the landbase experienced moderate to severe defoliation in several years during the outbreaks. The spatial historical patterns were

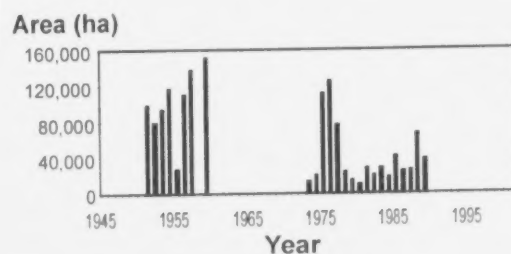


Figure 1. Area of moderate-severe defoliation in the Black Brook District since 1945.

characterized by length of the outbreak, annual and cumulative defoliation level, and return interval. Stand structure effects of spruce budworm defoliation were modelled using the STAMAN stand table projection model.

STAMAN incorporates pest impacts on growth and survival rates as functions of user-specified damage levels (Erdle and MacLean 1999). Spruce budworm impacts on a stand were quantified using STAMAN as change in volume over time and the tree diameter distribution by species over time. The following analysis present an example of the magnitude of effects of a budworm outbreak for spruce-balsam fir and balsam fir-hardwood stands.

Figure 2a,b shows an average reduction of 75% among diameter classes of spruce (*Picea* sp.) and a 92% reduction of balsam fir (*Abies balsamea* (L.) Mill.) from the spruce-fir stand, while the fir-hardwood stand experienced an 80% reduction in fir (Figure 2c,d). The resulting post-outbreak stands had a very different species/diameter composition. The non-outbreak spruce-fir stand was made up of 25% fir, 55% spruce, and 20% hardwood species but a severe outbreak leaves 6% fir, 39% spruce, and 55% hardwood. The outbreak left 22% fir and 78% hardwood in the fir-hardwood stand in contrast to 61% fir and 39% hardwood without the outbreak.

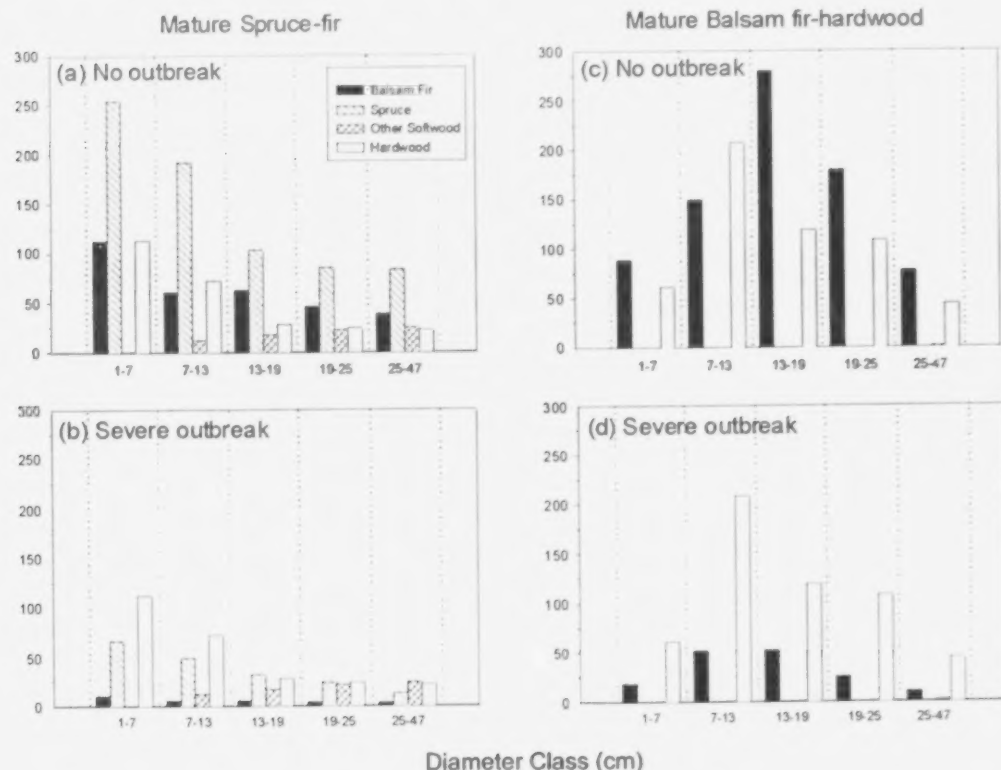


Figure 2. Simulated DBH distributions using STAMAN with and without spruce budworm outbreaks for spruce-fir and fir-hardwood stands. Mature spruce-fir (age > 80 years, > 80% susceptible species, spruce > fir) projected 15 years with (a) no budworm outbreak, and (b) a severe budworm outbreak. Mature balsam fir-hardwood (40-80 years, 50-80% susceptible species, fir > spruce, hardwood > than non-susceptible softwood) projected 15 years with (c) no budworm outbreak, and (d) a severe budworm outbreak.

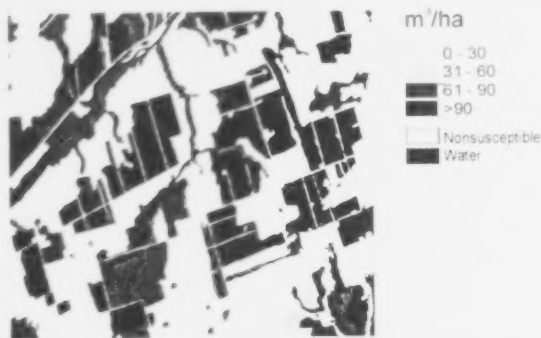


Figure 3. Map of estimated volume loss (m^3/ha) caused by a severe spruce budworm outbreak. The loss is calculated by the SBWDSS, at the scheduled time of harvest for the stand.

The effect of a spruce budworm outbreak on a particular landbase is an integration of the effects on all of the constituent stands. The overall magnitude of effects is influenced by stand characteristics: 1) budworm-caused mortality levels vary among fir and spruce and among mature and immature stands (MacLean 1980), 2) hardwood content (Su et al. 1996), and 3) site conditions (MacLean and MacKinnon 1997). The SBWDSS was used to simulate a number of different scenarios for the Black Brook District, allowing analysis of potential outbreak and management action effects at the landscape level. Figure 3 presents an example of the output derived from SBWDSS simulations. Using the management plan

for the landbase (yield expectations and harvest schedule), GIS-based forest inventory, defoliation history, future defoliation based on characteristic patterns, and the STAMAN model calibrated for spruce budworm, SBWDSS estimates a volume loss for each and every forest stand.

The characteristic outbreak patterns derived were used in SBWDSS simulations representing a natural non-managed landbase and simulations based on the actual industrial management plan. Simulations based on the 1946 forest condition were compared to present-day conditions. The ability to simulate future conditions based on natural disturbances as well as human ones provides guidance to forest managers trying to harmonize their management decisions with natural forest disturbances.

References

- Erdle, T.A., and D.A. MacLean. 1999. *For. Chron.* 75: 141-152.
- MacLean, D.A. 1980. *For. Chron.* 56: 213-221.
- MacLean, D.A. and W.E. MacKinnon. 1997. *Can. J. For. Res.* 27: 1859-1871.
- MacLean, D.A. et al. 2001. *Can. J. For. Res.* 31: 1742-1757.
- Su, Q. et al. 1996. *Can. J. For. Res.* 26: 1620-1628.

NOTES

Spatial Simulation of Forest Fire and Timber Harvesting in Missouri Ozark Highlands

Hong S. He¹, Stephen R. Shifley², William Dijak² and Eric J. Gustafson³

¹University of Missouri-Columbia, 203 ABNR Building, Columbia, MO, USA 65211 Tel.:(573)882-7717; E-mail: heh@missouri.edu

²U. S. Forest Service, North Central Research Station, 202 ABNR Building, Columbia, MO, USA 65211

³U.S. Forest Service, North Central Research Station, 5985 Highway K, Rhinelander, WI, USA 54501

Introduction

Although forest managers in the Midwest have good a understanding of the effects of silviculture and natural disturbances on stand development, the cumulative, landscape-scale effects of management decisions and natural disturbances are difficult to understand and predict. Nevertheless, it is often the landscape-scale management problems that are the most difficult to address due to the large spatial scales and long time frames involved. For example, forests in the Ozark Highlands of the Central Hardwood Region have experienced changes in size structure and species composition in the last 100 years that are now resulting in increased mortality of mature trees in the red oak group along with increased fuel loading and fire susceptibility. Mean fire return intervals that ranged from 3 to 16 years during the 1800s and early 1900s are now (through successful fire suppression efforts) on the order of 300 years. The open understory that had previously been maintained by periodic fires now has abundant woody vegetation. Many maturing oak forests have drought-stressed trees, high mortality rates, high fuel loads, and conditions that are vulnerable to catastrophic wildfires. Management activities can mitigate these effects, but not simultaneously on the millions of affected acres. In many cases, ecological questions involving large-scale processes, such as fire disturbance and timber harvesting, can best be answered with simulation models. Landscape modelling can help managers with (a) guidance about where the best opportunities are for management, (b) practices that can mitigate current

problems on the forest landscape, and (c) predictions of the long-term, cumulative effects that will result from management practices that are selected and applied. In this paper we discuss a spatially explicit and stochastic approach to simulate forest fire and timber harvest and their interactions with tree species in a large, heterogeneous landscape in the Ozark Highlands, Missouri, U.S.A.

The objectives are to examine (a) how forest fire interacts with natural succession, (b) possible species-level recovery after disturbance in managed landscapes, (c) interactions of forest harvesting and fire disturbance, and (d) the effects of fire suppression on landscape-scale forest dynamics.

Methods

Study Area

The study area is part of the Current River Watershed, Missouri Ozark highlands. It consists of about 250,000 acres (101,171 ha) in the central hardwood region, with white oak (*Quercus alba* L.) and black oak (*Quercus velutina* Lam.) as the dominant species. The abundance of short leaf pine is much lower than its historical level. Sugar maple (*Acer saccharum* Marsh.), a shade tolerant and fire intolerant species, has higher abundance due to decades of fire suppression. Age structure of this central hardwood forest is relatively simple as a result of historical cutting and more than a century of human activities.

LANDIS Model

We used the LANDIS model for our analysis. The major modules of the LANDIS model are forest succession, seed dispersal, wind and fire disturbances, and harvesting. LANDIS is a raster-based model. Each raster unit or cell is a spatial object that tracks: 1) the presence or absence of 10-year age cohorts of individual species, 2) fuel levels based on fuel accumulation and decomposition characteristics, 3) mean fire/wind return interval, 4) the time since last fire/wind/harvest disturbance, and 5) species establishment ability in particular environments. For each cell, species birth, growth, death, regeneration, random mortality, and vegetative reproduction are simulated at a 10-year time step. At landscape scales, seed dispersal, disturbances, and forest harvesting are simulated for each iteration. To simulate heterogeneous landscapes, ecoregions derived from other climate and soil GIS data layers are used to stratify the landscape. At a given focal resolution, such as within each ecoregion, environmental variables such as climate and soils are assumed homogeneous, as are characteristics such as mean fire return intervals, fuel decomposition rates, and species establishment.

Model Parameterization

Model parameters and results will be developed as follows:

1. Species and age composition maps (species90.gis) were derived from Landsat TM satellite imagery and forest inventory databases and land type maps (lu90.gis) were derived from a digital

elevation model (DEM). The attributes of each map are defined in species/age class attribute file (mapattrb.dat) and land type attribute file (landtype.dat), respectively.

2. Species vital attributes were parameterized in species.dat.
3. Mean fire return intervals of historical fire regime range from 10 years on savanna to 200 years on mesic land types. Mean fire return intervals are over 400 years on most land types under the suppressed fire regime.
4. The simulation will be run for 200 years.
5. The model will generate presence and absence maps (specified in the mapindex.dat), age distribution maps (specified in the ageindex.dat file), dominant map (classified from all individual species/age maps), for each species at each iteration.

Simulation Scenarios

We will simulate the natural fire regime (high fire frequency) and the fire regime under suppression (low fire frequency) with and without harvesting, for a total of 4 scenarios (Table 1).

Results and Discussion

Results and discussions will centre around the following questions:

1. What trends do we observe for the species trajectories for each of the 4 simulation scenarios (NN, NS, HN, HS)? Can we offer an explanation?
2. What are the effects of forest harvesting (comparison between NN and HN, and NS and HS)? Remember that the simulations start from a human-affected landscape (at year 0) and assumed no human intervention for the next 200

Table 1. Model simulation scenarios.

	Natural Fire	Suppressed Fire
No harvest	NN	NS
Harvest	HN	HS

years (except fire suppression for the low fire frequency scenario).

3. How does species age structure change for the high fire frequency scenario (comparison between NS and HS, and NN and HN)? Can we explain why?
4. Is there a fire suppression effect? What is it?
5. Can the trajectories of perimeter/area ratio and spatial distributions derived for white oak and short-leaf pine be used to explain the changes in spatial pattern and fragmentation (for all 4 scenarios)?
6. What do the results imply for fire risk management in Missouri Ozark Highlands?
7. What are the implications for managing central hardwood forests in Missouri?

NOTES

Spatial Simulation of the Large-Scale Forest Fire Regime in a Boreal Landscape

Ajith H. Perera¹, Dennis Yemshanov¹, Frank Schneckenger¹, David J. B. Baldwin¹, Kevin Weaver¹, and Den Boychuk²

¹Ontario Forest Research Institute, 1235 Queen St. E., Sault Ste. Marie, ON, P6A 2E5 Canada

²Integra Research, 5 Reed Dr., Ajax, ON, L1S 5S4 Canada

Introduction

Explicit portrayal of major disturbance dynamics is an essential prerequisite to emulating natural forest disturbances. In regions where large-scale forest fires are prevalent, this means understanding fire disturbance regimes and post-fire forest cover dynamics. This goal can be reached effectively through spatially explicit models that simulate fire disturbance dynamics over large spatial extents. While landscape disturbance modelling is an increasingly popular research topic, knowledge gaps still exist in the landscape-scale modelling of integrated fire disturbance dynamics in the North American boreal biome. Some notable weaknesses include:

- Excessive reliance on empirical and statistical assumptions of disturbance dynamics instead of process-based logic
- Implicitness of scale and spatial effects in simulated processes
- Inadequate stochasticity in model realizations

In this context, our goal here is to describe the development and use of the **Boreal FOrest Landscape Dynamics Simulator (BFOLDS)**, a mechanistic simulation model that spatially predicts the medium-term fire regime for the boreal biome of Canada.

Model Description and Simulation Runs

BFOLDS is an integrated disturbance regime model, composed of a fire regime simulator

module and a vegetation transition simulator (Figure 1). It is designed to predict forest landscape dynamics over large areas (10 M ha), for medium terms (up to 300 years), at 1-year time steps and 1-ha spatial resolution. The fire simulation module is process-based, and contains sub-modules of fire ignition, fire spread, and fire extinguishment. These processes use hourly varying fine fuel moisture code, duff moisture code, and buildup indices of the Canadian Fire Weather Index System. The weather patterns are simulated using a 40-year history of spatially explicit daily weather and wind speed/direction surfaces. Terrain (slope and aspect) and water bodies are used to constrain fire growth, frontal intensity, and the rate of fire spread. This module does not use empirical assumptions of fire size distribution, but explicitly simulates the processes of fire behaviour on a cell-by-cell basis.

The vegetation transition module simulates 2 processes: the post-disturbance recruitment of tree species and subsequent forest cover succession. The first step is based on a simplified version of Harper's model of plant regeneration and on published knowledge of tree species regeneration ecology. The second step is simulated as a semi-Markovian transition process, by using probabilistic functions of tree species persistence in the canopy, published post-disturbance successional pathways and spatial data on site conditions such as geoclimate, soil moisture, and nutrient status. BFOLDS also contains a sub-module that applies spatial bias to transition probabilities of forest cover change using local spatial autocorrelation of environmental site conditions. This step reduces the artificial spatial randomness introduced by

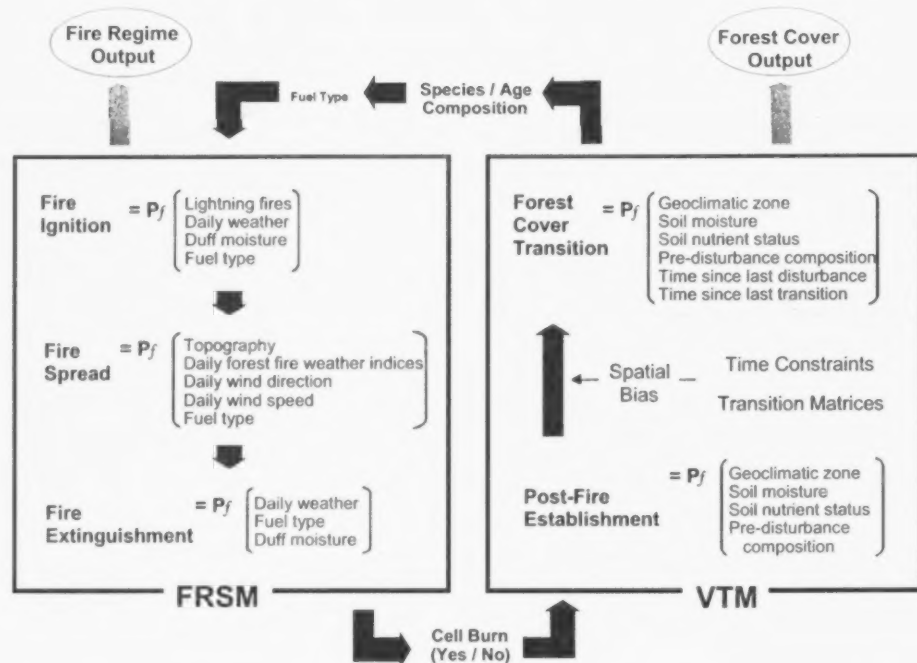


Figure 1. Conceptual overview of the Boreal Forest Landscape Dynamics Simulator (BFOLDS) model (FRSM = fire regime simulation module, VTM= vegetation transition module).

Table 1. Information output from the Boreal Forest Landscape Dynamics Simulator (BFOLDS).

Annual Statistics	Overall Statistics
Fire regime Number of burns Total area burned Spatial geometry of burns Size-class distribution of burns	Fire Regime Temporal variation of number of burns Temporal variation of area burned Spatial tendency of burns Fire return interval Spatial tendency of fire return interval Spatial geometry of burns Size-class distribution of burns
Landscape Structure Species composition Canopy age composition Site age composition Spatial geometry	Landscape Structure Survivorship distribution Temporal variation of canopy age-class distribution Temporal variation of site age-class distribution Spatial tendency of landscape aging (canopy) Spatial tendency of landscape aging (site) Temporal variation of species composition Spatial tendency of species occurrence Spatial tendency of species-age occurrence

stochastic elements in the modelling steps. We selected a 2 million ha region of managed forest landscape from boreal Ontario to demonstrate the use of BFOLDS in simulating fire disturbance regime. The geospatial data (climate zonation, soil, terrain, recent fire history, forest cover and canopy age composition) were generated from published and intra-agency data sources. A 10-km wide buffer was added to the study area to account for fires that

ignite outside and spread into the area. We used 20 replications of 200-year runs to capture the range of temporal, spatial, and morphological variation of the fire disturbance dynamics. These case study simulations were made without initializing the forest cover composition, using forest cover and canopy age data from the recent forest inventory. A wide array of spatially explicit information is generated by BFOLDS (Table 1).

NOTES

Emulating Natural Forest Patterns in the Inland Northwest, USA

Paul F. Hessburg¹, Keith M. Reynolds, R. Brion Salter and Merrick B. Richmond

¹USDA Forest Service, Pacific Northwest Research Station, 1133 North Western Avenue, Wenatchee, WA, USA 98801, Tel: (509)664-2709; E-mail: phessburg@fs.fed.us

Introduction

Over the last 200 years, the combined effects of settlement, exploitation, management, and the loss of Indian burning have markedly altered the natural patterns of Inland Northwest US forests. Landscape-scale patterns of forest structure, composition, snags, and down wood have been transformed, fire and other disturbance regime parameters in many dry and mesic forests have shifted toward increased severity and extent, and the natural ebb and flow of terrestrial and aquatic habitats and linkages has been disrupted. Here, we describe methods for characterizing range and variation in natural forest patterns for the purpose of emulating them through restorative treatments. We compare the current patterns of an example watershed (WEN13) with estimates of reference variation from its corresponding subregion, and discuss applications to landscape pattern restoration.

Materials and Methods

To estimate the range and variation of natural patterns we: (1) grouped Inland Northwest watersheds (5,000 to 10,000 ha) into biogeoclimatic subregions using multivariate techniques; (2) mapped the historical vegetation of a random 15% sample of watersheds of one subregion (ESR4 - Cool/Moist Cascades Forests) from 1930s -1940s aerial photography; (3) statistically reconstructed the vegetation attributes of all historical polygons that showed any evidence of prior timber harvesting; and (4) estimated ESR4 reference conditions for spatial patterns of forest composition, structure, modelled ground fuel, and several fire behaviour

attributes using a parsimonious set of class and landscape metrics, and a spatial pattern analysis program (FRAGSTATS). We programmed ESR4 reference conditions into the EMDS decision support tool, mapped the current vegetation patterns of the ESR4 watershed WEN13, and objectively compared them with reference conditions.

Results and Discussion

The comparison showed that historical disturbance processes created a broad range of vegetation patterns that reinforced infrequent stand-replacing and mixed severity fires, and thereby, abundant late-successional and old forests. Timber harvesting substantially altered these patterns and interactions. Selection cutting removed large overstory Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and ponderosa pine (*Pinus ponderosa* Laws.) from old forest multi-story structures (ofms) reducing their area and connectivity, and increased the area of intermediate forest structures (secc, ur, yfms, Table 1). Regeneration harvests increased newly regenerated forest area (si, Figure 1). Collectively, late-19th and 20th century timber harvests increased the dominance of late-seral cover types while diminishing early-seral species cover (Table 1). Changes in the pattern and abundance of structural classes and cover types were reflected in current spatial patterns of ground fuels and fire behavior attributes (Figure 1). Spatial patterns of historical vegetation and fuels favored simple and contagious fire patterns. Current conditions no longer support these dynamics (Figure 1). Managers can use estimates of reference conditions to: (1)

Table 1. Comparison of current conditions in watershed WEN13 with RV (reference variation) estimates of the ESR4 - Cool/Moist Cascades Forests subregion, where patch types were forest cover type-structural class doublets.

%Land ¹				PD (n/10,000 ha)			MPS (ha)		
Structure class	WEN13	RV (80% range)		WEN13	RV (80% range)		WEN13	RV (80% range)	
		min	max		min	max		min	max
Ponderosa pine									
si ²	1.4		0.0	1.1	4.0	*	0.0	2.0	34.4
0.0	38.1								
seoc	0.5		0.0 2.1	3.0	0.0	5.0	15.3	0.0	38.6
secc	0.7	*	0.0 0.0	4.0	*	0.0 0.0	16.1	*	0.0 0.0
ur	0.4		0.0 2.1	2.0		0.0 2.0	20.7		0.0 45.7
yfms	0.6		0.0 1.9	5.0	*	0.0 3.0	11.1		0.0 87.8
ofms	3.0	*	0.0 2.3	2.0	*	0.0 1.0	144.8	*	0.0 34.3
ofss	0.3		0.0 1.3	1.0		0.0 3.0	26.6		0.0 33.3
Douglas-fir									
si	4.1		0.0 8.4	44.0	*	0.0 14.0	9.3	0.0	57.1
seoc	4.1		0.0 9.2	23.0	*	0.0 15.0	18.0	0.0	128.8
secc	3.6		0.0 14.9	21.0	*	0.0 13.0	17.1	0.0	195.7
ur	4.0		0.4 19.5	20.0		0.1 24.0	20.3	17.0	175.6
yfms	3.0		0.6 9.3	17.0		0.3 23.0	18.0	10.6	74.8
ofms	7.5		0.0 12.5	17.0	*	0.0 15.0	44.5	0.0	271.0
ofss	4.1		0.0 4.6	4.0	*	0.0 7.0	98.8	0.0	128.9
Western larch									
si	0.3	*	0.0 0.2	1.0	0.0	1.0	25.4	*	0.0 17.6
yfms	0.2		0.0 0.3	1.0	0.0	1.0	14.6	0.0	15.1
Grand fir									
si	0.1	*	0.0 0.0	1.0	*	0.0 0.0	4.6	*	0.0 0.0
seoc	0.1		0.0 0.3	1.0		0.0 1.0	7.6	0.0	13.5
yfms	0.3	*	0.0 0.1	2.0	*	0.0 0.0	15.4	*	0.0 8.6
ofms	0.3	*	0.0 0.0	4.0	*	0.0 0.0	6.4	*	0.0 0.0
Pacific silver fir									
si	3.0	*	0.0 2.6	12.0	*	0.0 8.0	26.4	0.0	43.5
seoc	1.1		0.0 4.5	8.0		0.0 14.0	13.6	0.0	84.6
secc	0.5		0.0 13.1	3.0		0.0 14.0	14.2	0.0	118.1
ur	3.4		0.0 10.0	12.0		0.0 18.0	29.4	0.0	91.4
yfms	1.7		0.0 6.1	10.0		0.0 14.0	15.9	0.0	73.4
ofms	1.9		0.0 2.4	2.0		0.0 4.0	92.2	*	0.0 57.2
ofss	0.2		0.0 2.5	2.0		0.0 4.0	10.8	0.0	90.0
Subalpine fir/Engelmann spruce									
si	1.3		0.0 12.8	15.0	*	0.0 14.0	9.2	0.0	87.3
seoc	3.3		0.3 3.3	16.0	*	1.0 13.0	20.8	10.4	54.4
secc	0.2		0.0 2.5	3.0	*	0.0 4.0	6.8	0.0	75.1
ur	4.4		0.0 11.0	20.0	*	0.0 13.0	22.3	0.0	163.1
yfms	6.7		0.2 12.7	30.0	*	1.0 24.0	22.0	19.2	69.7
Western hemlock/Western redcedar									
seoc	3.0	*	0.0 1.1	5.0	*	0.0 4.0	57.0	*	0.0 47.9
secc	0.2		0.0 6.6	1.0		0.0 6.0	15.8	0.0	100.3
ur	5.9		0.0 8.7	13.0	*	0.0 6.0	46.6	0.0	288.8
yfms	1.5	*	0.0 1.2	4.0	*	0.0 3.0	36.2	0.0	40.5
ofms	7.1	*	0.0 1.8	16.0	*	0.0 5.0	44.9	0.0	74.1
ofss	1.2		0.0 4.7	8.0	*	0.0 3.0	14.7	0.0	143.5
Mountain hemlock									
secc	0.1		0.0 0.8	1.0	0.0	1.0	8.4	0.0	52.8
ur	0.4		0.0 2.3	2.0	0.0	3.0	16.6	0.0	83.7
yfms	0.2		0.0 2.5	1.0	0.0	5.0	17.5	0.0	31.3
ofms	0.3		0.0 0.4	1.0	0.0	0.0	25.7	*	0.0 12.9

¹%LAND = percentage of the landscape area; PD = patch density; MPS = mean patch size

²si = stand initiation; seoc = stem exclusion open canopy; secc = stem exclusion closed canopy; ur = understory regeneration; yfms = young forest multi-story; ofms = old forest multi-story; ofss = old forest single story. Asterisk (*) indicates that the current value for the metric is outside the estimated reference variation (RV) which is nominally the sample median 80% range of the metric.

evaluate current conditions and estimate consequences to native species and processes; (2) assess alternative landscape patterns and evaluate opportunities and risks to native species, processes,

and ecosystem productivity; (3) develop pattern restoration goals; and (4) set restoration priorities across broad geographic areas.

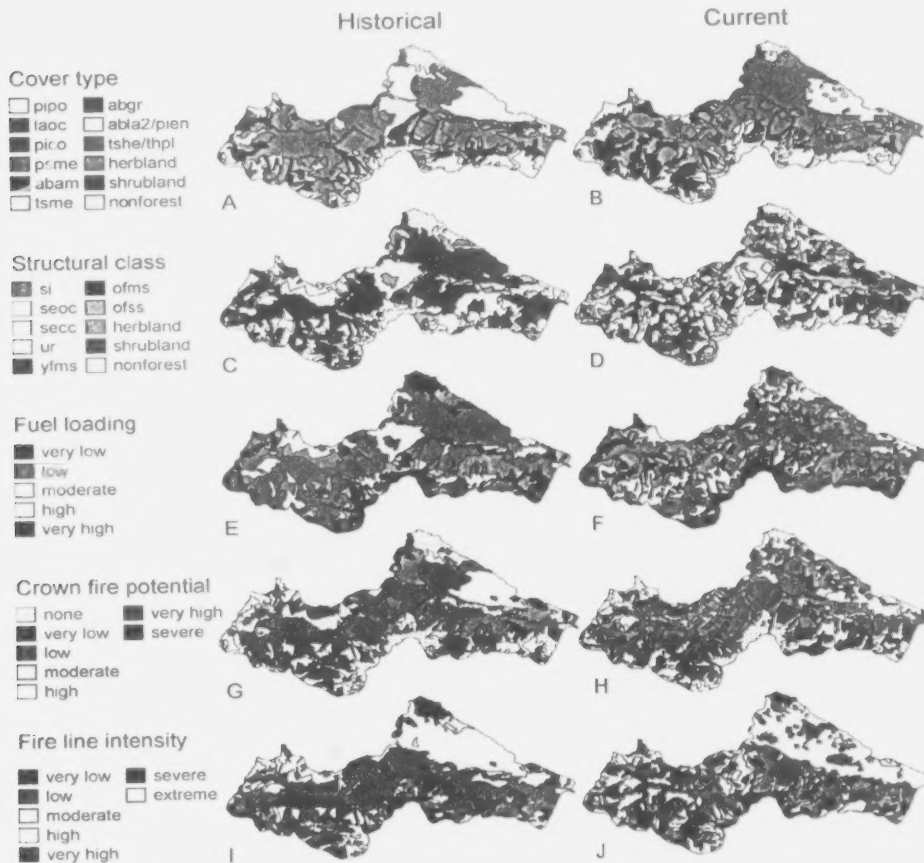


Figure 1. Maps of subwatershed WEN13 of the Wenatchee River drainage in the eastern Washington Cascades displaying historical (1900s) and current (1990s) cover types (A&B), structural classes (C&D), fuel loading (E&F), crown fire potential under wildfire conditions (G&H), and fireline intensity under wildfire conditions (I&J), respectively. Cover types are: pipo = ponderosa pine; laoc = western larch; pico = lodgepole pine; psme = Douglas-fir; abam = Pacific silver fir; tsme = mountain hemlock; abgr = grand fir; abla2/pien = subalpine fir/Engelmann spruce; tshe/thpl = western hemlock/western redcedar. Structural classes are: si = stand initiation; seoc = stem exclusion open canopy; secc = stem exclusion closed canopy; ur = understory reinitiation; yfms = young forest multi-story; ofms = old forest multi-story; and ofss = old forest single story. Fuel loading classes are: very low < 22.5 Mg/ha; low = 22.5-44.9 Mg/ha; moderate = 45-56.1 Mg/ha; high = 56.2-67.3 Mg/ha; and very high > 67.3 Mg/ha. Crown fire potential classes were a relativized index. Fireline intensity classes were: very low < 173 Kw/m; low = 173 - 345.9 Kw/m; moderate = 346 - 1,037.8 Kw/m; high = 1,037.9 - 1,729.6 Kw/m; very high = 1,729.7 - 2,594.4 Kw/m; severe = 2,594.5 - 3,459.2 Kw/m, and extreme > 3,459.2 Kw/m.

NOTES

Implementing Natural Disturbance-Based Management in the Black Spruce Forest of Northwestern Quebec: From Ideas to Reality

Sylvie Gauthier^{1,2}, Thuy Nguyen³, Yves Bergeron^{2,3}, Alain Leduc^{2,3}, Pierre Drapeau^{2,3} and Pierre Grondin⁴

¹ Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Center, Sainte-Foy, QC, G1V 4C7 Canada Tel.: (418)648-5829; E-mail: sgauthier@cfl.forestry.ca

² Groupe de recherche en écologie forestière inter-universitaire (GREFi), UQAM

³ UQAT-UQAM NSERC Industrial Chair in Sustainable Forest Management

⁴ Quebec Ministry of Natural Resources

Introduction

Forest ecosystem management that is based on the understanding of natural disturbance regimes has recently been suggested as a means to maintain biological diversity and productivity in forest systems. Figure 1 illustrates such a management strategy as proposed for black spruce (*Picea mariana* (Mill.) B.S.P.)-dominated forests. The forest dynamics model illustrated in the figure suggests that the current diversity of forest types on the landscape reflects the natural disturbance regime present across it. The model also proposes that the use of a variety of silvicultural treatments will help to maintain the diversity of forest types. This paper illustrates the development and implementation of a forest ecosystem management strategy in northwestern Quebec based on this model.

Methods

The development of the strategy is based on data obtained from 3 different research themes. Each theme focuses on a different aspect of the model and encompasses several research projects carried out in the Matagami ecoregion. The themes are:

- Documenting and characterizing the historical natural disturbance regime, notably fire frequency, size and, severity
- Documenting and characterizing natural forest dynamics and the response of organisms to the change in forest composition and structure

- Documenting the effects of different silvicultural treatments on various stand components and biological diversity

The knowledge acquired in these research themes serves as a basis to implement the strategy in a pilot territory covering more than 4500 km². This implementation is accomplished through a fourth research theme:

- Establishing management objectives for the pilot management unit, assessing the impacts of different management strategies, and developing tools that will facilitate the implementation of the strategy at different levels of forest management planning

Results and Discussion

A fire history reconstruction has shown that fire frequency within the study area has varied over the last 300 years resulting in an elongation of the fire return interval: 80 years before 1850, 150 years between 1850 and 1920, and 325 years since 1920. Furthermore, analysis of the last 60 years of fire records from the Quebec Ministry of Natural Resources has indicated that fires ranging from 950 to 20,000 ha could be considered characteristic for the black spruce zone of western Quebec. Although they account for less than 10% of occurring fire events, fires of 1000 ha or more generate close to 90% of the burned areas. Finally, the examination of 16 fire severity maps shows that although the proportion of unburned forest

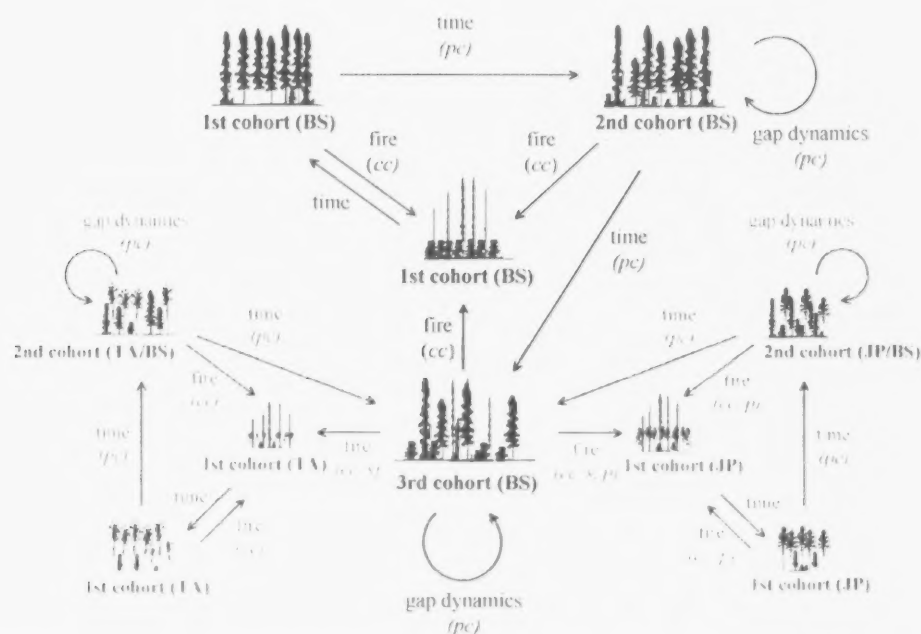


Figure 1. Natural dynamics and proposed silviculture for the black spruce forest. Stand composition: black spruce (BS), jack pine (JP), trembling aspen (TA). Silvicultural intervention: clearcutting (cc), partial-cutting (pc), site preparation (s), planting (p).

(preserved islands) was relatively constant (5%), the proportion of partially burned forest varied from 30 to 50%, while 45 to 65% of the forest was severely burned. These 3 studies demonstrate that fire frequency, size, and severity are all characterized by a certain range in variability.

This disturbance regime generated the forest mosaic that now occurs on the landscape. For example, 57% of the study area is composed of forests that burned more than 100 years ago, while 20% is composed of forests that are older than 200 years. This suggests that under a natural disturbance regime, a significant proportion of the stands in the region have been exempted from fire for long time periods and that there exists a natural forest dynamics that describes the changes that occur within a forest stand over time. The results of several studies conducted in the study area show that the intervals between successive fires on a particular site have a strong influence on forest structure and, to a lesser extent, tree composition.

For example in stands older than 100 years, canopy density and height tends to decrease with increasing time since the last fire. Furthermore, analyses show that forest dynamics are influenced by the underlying surficial deposits. The presence and abundance of species (birds, insects, vascular, non-vascular plants) gradually change along the time since fire sequence, with very few species restricted to a particular stand age.

Baseline data on the response of organisms to the natural dynamics of the forest mosaic was a prerequisite for assessing key differences that possibly exist in biodiversity patterns between managed forests and naturally disturbed forests. Several studies aiming at evaluating the effects of different silvicultural treatments on forest stand components and biological diversity are now being conducted in the study area. Preliminary results suggest that partial cutting will maintain or produce forest stand structures characteristic of older forests.

Results obtained from the 3 first research themes are currently being used to develop tools and guidelines that will facilitate the implementation of the proposed strategy. This requires the integration of a number of elements related to natural disturbance regime and natural forest dynamics at different levels of forest management planning. For example, the development of a 25-year strategic plan requires the establishment of management objectives at a landscape level. We propose that a management strategy based on the use of a variety of silvicultural systems (even-aged and uneven-aged) will maintain the observed natural diversity resulting from the fire regime variability in terms of size, severity, and intervals. Preliminary results indicate that the implementation of such a strategy would not significantly affect timber supply while favouring the maintenance of a variety of stand types.

Implementing the strategy in a 5-year tactical plan requires the development of tools for evaluating the potential for the different silvicultural

systems in different management subunits. It also requires the development of guidelines for the spatial and temporal distribution of these different silvicultural systems. So far, our analyses indicate that implementation of the strategy at this level of forest management planning is mainly limited by the nature of the information available in forest resource inventories. Finally at the 1-year operational planning level, field guides are being developed as tools for silvicultural diagnostic, prescription, and evaluation in the context of mixed silvicultural systems.

Implementation of the proposed strategy is a good example of adaptive management. The continual arrival of new results from the first 3 research themes facilitates and improves the development of tools and guidelines stemming from the fourth research theme. In this regard, monitoring the managed forests is an integral part of the strategy and can easily be incorporated in the different research themes.

NOTES

Emulating Natural Forest Disturbances in the Wildland-Urban Interface of the Greater Yellowstone Ecosystem

William H. Romme¹, Monica G. Turner², Daniel B. Tinker³ and Dennis H. Knight⁴

¹Colorado State University, 104 Forestry, Fort Collins, CO, USA 80523 Tel.: (970)491-2870; E-mail: william.romme@colostate.edu

²University of Wisconsin

³Western Carolina University

⁴University of Wyoming

The Greater Yellowstone Ecosystem (GYE) encompasses Yellowstone and Grand Teton National Parks, plus various national forests, other public lands, and extensive tracts of private lands. Although the GYE contains the largest expanse of wild country in the continental USA, it also is where the human population on private lands is increasing most rapidly. An urgent land management question in the region is how to maintain a natural fire regime in the region's large national parks and wilderness areas while also reducing wildfire hazard on private lands.

In this paper, we identify and evaluate possible strategies for managing fire at the wildland-urban interface in the GYE. In particular, we examine a key approach being developed for some forest types elsewhere in the West, notably ponderosa pine forests. This approach emphasizes mechanical thinning of dense forest canopies followed by repeated low-intensity burning. We present the reasons why such a strategy is probably unworkable and inappropriate in most forests of the GYE, and suggest an alternative fire management strategy that would more closely maintain the natural disturbance regimes of the GYE.

The management strategies that we review here are intended for private and public lands in the immediate vicinity of human communities and other developed areas. Within the large national parks and wilderness areas of the GYE, we advocate a natural fire policy that permits fire to

operate much as it did before Euro-American settlement of the region. These areas are large enough, and ecologically intact enough, to absorb even fires of the magnitude of the 1988 Yellowstone fires. As such, they are of great value as examples of natural landscape structure and ecosystem function. It is in the wildland-urban interface that natural disturbance processes and vulnerable human structures and institutions collide.

Natural Disturbance Regimes in the GYE

The GYE encompasses a diversity of vegetation types across a wide range of conditions of elevation, geologic substrate, and topography. From lowest to highest elevations, the major upland vegetation types include: sagebrush-grasslands, Douglas-fir (*Pseudotsuga menziesii* (Mill.) Franco) forests, aspen (*Populus* sp.) forests, lodgepole pine (*Pinus contorta* Dougl.) forests, spruce-fir (*Picea* sp. – *Abies* sp.) forests, whitebark pine (*Pinus albicaulis* Engelm.) forests, and alpine meadows and barrens. Distinctive riparian vegetation also is found along streams, lakes, and wetlands.

Nearly all of these vegetation types have a long history of periodic fires. Historical intervals between successive fires range from a few decades in some sagebrush-grassland areas at the lowest elevations, to several centuries in the lodgepole pine, spruce-fir, and whitebark pine forests at the

highest elevations. Although lightning ignites numerous fires every summer, the majority of these fires remain very small (less than a hectare or 2) because they ignite during damp weather and they do little damage to the vegetation. A handful of fires ignited under dry weather conditions grow larger, however, and it is these few large fires that account for most of the area burned. These large fires also tend to burn at high intensity and to kill all of the aboveground vegetation within the burned area. It is important to emphasize that the well-publicized natural fire regime of southwestern ponderosa pine (*Pinus ponderosa* Laws.) forests – frequent, low-intensity fires that thin the forest but kill few canopy trees – is not characteristic of most forests in the GYE, because of fundamental differences in climate, species, and fuel conditions.

Although large fires in the GYE tend to burn at high intensity and to kill most or all of the aboveground vegetation, the ecosystems in this region are very resilient to fire. Because of the long history of fires, all of the organisms have mechanisms that allow them to survive – even thrive – in the face of high-intensity fires. For example, some lodgepole pine trees have cones that do not release their seed at maturity. Instead, the cones remain sealed until subjected to high temperatures, as in a fire. The fire kills the adult lodgepole pine, but stimulates the release of abundant seeds onto bare ground, which is an ideal seedbed for young pine seedlings. Most herbaceous plants on the forest floor have their tops burned off by the fire, but the belowground parts generally survive. Within a year or two after the fire, these surviving roots, rhizomes, and other plant structures resprout and grow profusely. We have followed the recovery of forest communities since the 1988 Yellowstone fires and found that plant cover and species diversity return to pre-fire levels within a decade or less in most areas. Basic ecosystem processes, like productivity and nutrient cycling, also were restored within a few years in most of the burned area. Thus, even though fires are sometimes

spectacular and seemingly destructive in the GYE, the natural fire regime really is not a threat to biological diversity or ecological integrity in this ecosystem.

The Wildland Urban Interface and Wildfire Hazard in the GYE

The GYE is one of the fastest growing areas in the United States, in part because of the aesthetic and recreational amenities that it provides. The economic base of the region has shifted from the extractive industries (e.g., logging and mining) that dominated throughout the early and middle 20th century, to a new economy based on services, amenities, and land development. Much of the development in the GYE is exurban, i.e., located outside the boundaries of incorporated towns and villages. Because many of the new ranchettes and dispersed subdivisions lie outside the jurisdictional boundaries of local governments, much of the growth in the GYE is occurring rapidly but with little or no comprehensive planning or regulation. Many of the new subdivisions are being built within very flammable vegetation types, e.g., lodgepole pine and sagebrush. The costs of this uncontrolled development – ecological, economic, social, and political – have only begun to be assessed.

The wildfire hazard in exurban areas throughout the Rocky Mountains has become increasingly apparent in the last few years. The large, destructive fires in Los Alamos, New Mexico, and along Colorado's Front Range in 2000 underscored the dangers of living within a fire-dependent ecosystem. The U.S. government issued the national fire plan in 2000, which calls for several steps designed to reduce the wildfire hazard throughout the country. One component of the fire plan is fuel reduction in the wildland-urban interface. Fuel reduction may be accomplished mechanically, by selective logging or thinning of dense forest canopies, or with low-intensity prescribed fire, or through a combination of both thinning and

burning. Large-scale programs are underway in the vicinity of Flagstaff, Arizona, and other communities to reduce the chances of uncontrollable wildfires destroying homes and taking lives.

Fuel reduction programs also have been initiated recently in the GYE. Within the immediate vicinity of vulnerable homes and other structures, such reduction makes good sense, and we support efforts to encourage homeowners to protect their homes. The issue that we address in this paper, however, is whether broad-scale fuel reduction within the extensive forests that surround subdivisions, would be effective or appropriate in this system. We argue that extensive fuel reduction efforts would be neither effective at preventing wildfire losses, nor ecologically appropriate for this ecosystem.

Why Mechanical Thinning and Prescribed Fire are Inappropriate in GYE

We argue against broad-scale thinning and burning programs in the GYE because of several important operational and ecological problems that would be associated with such a program. The operational problems include (i) the low economic value of most of the wood that would be removed in a thinning operation, such that the process would have to be almost entirely subsidized, and (ii) the difficulty of conducting low-intensity prescribed burning in lodgepole pine forests. The window of opportunity for burning this type of forest is very narrow: if conditions are slightly wetter, the forest will not ignite; if slightly drier the fire will become an uncontrollable crown fire.

Ecological problems include the following: (i) Thinning increases vulnerability to windthrow in lodgepole pine, which could lead to loss of most of the residual canopy. (ii) Lodgepole pine, spruce, and fir are not fire-resistant, and much of the residual forest canopy might be killed by even a low-intensity fire. (iii) The ground-layer species respond to fire by prolific resprouting. We hypothesize that they require lots of root reserves for these sprouts. If they were burned repeatedly at short intervals, they might not have the energy reserves to keep resprouting, and could be locally extirpated. (iv) Loss of some native herbaceous species through short-interval burning could create opportunities for invasion of non-native species, followed by permanent changes in species composition. The naturally infrequent fires that characterize this ecosystem create only limited opportunities for invasive species.

Alternative Fire Management Strategies for the GYE

Mechanical fuel reduction should be encouraged in localized areas immediately around homes and other structures. However, the goal of this kind of treatment should be purely to create local defensible space. In surrounding forested areas, away from the immediate vicinity of homes and other vulnerable structures, something close to the natural fire regime should be maintained. Homes and other vulnerable structures should be clustered within small portions of the landscape, leaving large tracts of undeveloped land between the clusters where the natural, infrequent but high-intensity fires could be allowed. We will further develop this idea in the paper.

NOTES

Simulating Forest Fire Regimes in the Canadian Rocky Mountain Foothills

Chao Li

Canadian Forest Service, Northern Forestry Centre, 5320 – 122 Street, Edmonton, AB, T6H 3S5 Canada
Tel.: (780)435-7240; E-mail: cli@nrcan.gc.ca

Introduction

It is believed that sustainable forest resources and healthy biodiversity can be achieved through emulating natural disturbance (primarily fire) patterns in the practice of resource management. The belief requires scientific support in terms of a better understanding of natural fire patterns. Most available data on historical fire patterns, however, were collected under various fire management scenarios. Questions such as what are the differences between fire regimes under natural and managed conditions must be resolved to support this concept.

Methods

Observed fire regime, under a fire suppression scenario, was described using statistics from an analysis of spatial and non-spatial historical forest fire records of Alberta. Because appropriate empirical data is not available for Alberta's natural fire regime, a spatially explicit model of forest dynamics (SEM-LAND) was used to reconstruct the natural fire regime of a study area in the west-central Alberta. Figure 1 shows the input maps for the SEM-LAND model.

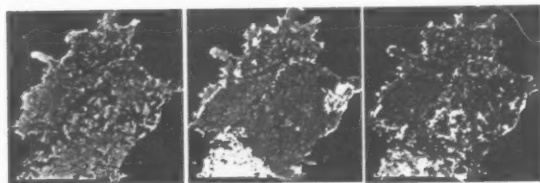


Figure 1. Forest cover type (a), forest age (b), and site index (c) of a study area in west-central Alberta (area is 31,444 ha; resolution 1 ha; Athabasca working circle compartments 28, 29, 31, and 32).

Results

The observed fire regime for the study area showed that:

- 53.1% of fires were caused by lightning strikes, and these burned 84.2% of the total burned area
- 25.6% of fires were ground fires, and these burned only a very small portion of total burned area (0.3%). On the other hand, 8.7% of fires were crown fires, which burned a large portion of total burned area (56.3%)
- Fire cycle estimated from this data set was 843.6 years
- Discontinuous fire size distributions can be identified for ground, surface, and crown fires

The simulated fire regime in the study area indicated that:

- The fire cycle under fire suppression is 675.6 years, ranging from 427.7 to 1,523.4 years, and the fire cycle under natural conditions is 104.6 years, ranging from 96.1 to 108.0 years
- Fire size distributions are discontinuous, and a negative exponential probability distribution cannot characterize them properly
- A relative fire probability map was constructed (Figure 2) based on long-term interactions among fire events, landscape structure, and conditions of forest, weather, and fuel

Discussion

- Observed fire regimes are natural fire regimes modified by human activities. Human influence on natural fire regimes includes mainly changes

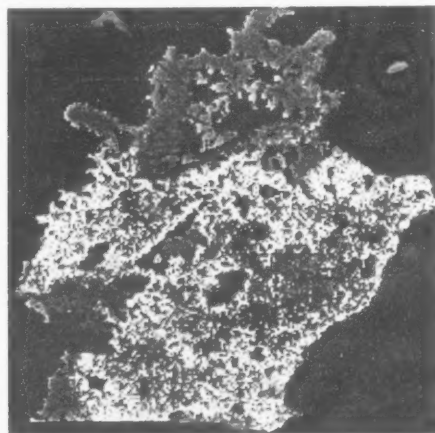


Figure 2. Relative fire probability map constructed from fire regime simulations under natural conditions in a study area in west-central Alberta (area 31,444 ha; resolution 1 ha).

in fire ignition source patterns and fire spread processes

- Several components of a natural fire regime can be obtained from historical fire records, such as ignition source patterns in terms of spatial

distribution and mean annual number of natural fire ignition sources for a given region

- Descriptions of fire regimes for various types of forests differ depending on research approaches and sampling design
- Since fire is recognized as a semi-random process, emulating fire pattern should not aim at any specific fire event, but the average situation over the long term
- Natural fire regime maps and/or relative fire probability maps, based on long-term interactions among ecosystem components, are useful information for forest management decision-making
- Constant changes in ecosystem dynamics must be considered to achieve the goal of sustainable forest management
- More attention should be paid to the construction of natural fire regime maps and/or relative fire probability

NOTES

Empirical/Statistical Approaches to Modelling Wildland Fire in the Pacific Northwest, USA

Donald McKenzie¹, Susan Prichard², Amy E. Hessl³, and David L. Peterson¹

¹USDA Forest Service, Seattle Forestry Sciences Lab, 4043 Roosevelt Way NE, Seattle, WA, USA 98105-6497 Tel.: (206)732-7810; E-mail: donaldmckenzie@fs.fed.us

²College of Forest Resources, University of Washington

³Department of Geology and Geography, West Virginia University

Introduction

Accurate, spatially extensive empirical data are a prerequisite for the effective application of management strategies in forested landscapes. For many regions these data either do not exist or are not processed and summarized to be most useful for managers (Table 1).

In the Pacific Northwest, USA, rugged topography and steep climatic gradients make extrapolation and interpolation from existing data points especially difficult. Given these limitations, it is still important to provide managers with data and models that represent existing knowledge in an interpretable form applicable at multiple spatial scales. We used empirical modelling of linkages among the temporal dynamics of fire, climate, and vegetation to create data layers at multiple spatial and temporal scales, which can be applied to management at watershed to regional scales in the Pacific Northwest. In this paper we report on 3 projects:

- A regional-scale model to predict historical fire-return intervals

- Spatially explicit models of variability in fire regimes
- A reconstruction of Holocene fire frequency, linked to climate and macrofossils

Materials and Methods

Regional-scale model of fire-return intervals:

We developed weighted multiple regression models to predict fire-return intervals (FRIs) in the interior Columbia River Basin (ICRB), USA, from geographic coordinates, climate (summer precipitation), and vegetation (dominant cover types). We extracted historical FRIs from 190 sites in the Basin from a fire history database for the continental USA (Heyerdahl et al. 1995). Dominant cover types were extracted from the ICRB coarse-scale simulation effort (Keane et al. 1996), and precipitation from the PRISM coverages (Daly et al. 1994).

Spatially explicit models of variability in fire regimes: We used parametric models to estimate the distributions of fire intervals at multiple spatial scales across eastern Washington, USA, using an

Table 1. Key problems presented by empirical data (resolution, extent, and spatial pattern) that affect the success of large-scale fire modelling and management.

Climate data	Fire history reconstructions	Vegetation/fuels and topography
Limits of temporal extent and resolution of instrumental data	Fire history sites do not span the range of environmental variability of modelled sites	Fire history sites do not span the range of environmental variability of modelled sites
Interpolation or extrapolation in complex terrain	Data points clustered, so difficult to interpolate	Data points clustered, so difficult to interpolate

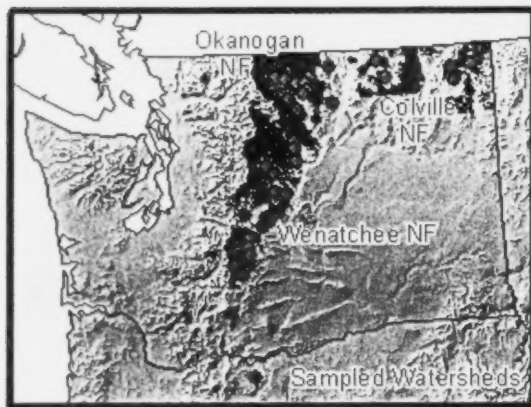


Figure 1: Watersheds in eastern Washington, USA, in which spatially referenced fire-scar data were collected.

extensive, geo-referenced database of fire scars (Figure 1). We also used time-series methods to identify relationships among climatic indices and variability in fire regimes over the period 1700-1900 (historical period).

Reconstruction of Holocene fire frequency:

We sampled sediments from a small (0.3 ha) montane lake within a transitional climate zone of North Cascades National Park (NCNP). Sediment cores were sliced into 1-cm sections which were then sieved into $>500\mu\text{m}$ and $150\text{--}500\mu\text{m}$ fractions. We counted charcoal fragments from both fractions in order to estimate the intensity of fire events over time. Macrofossils from the larger fragment were identified and counted in order to estimate the relative abundance of different tree species over time, and to link fluctuations in abundance with fire events.

Results and Discussion

We identified 2 optimal models of FRIs in the ICRB (Figure 2); the second model downweights less reliable data more severely, and as a result excludes about 30% of the fire history sites. FRIs generally increase from south to north within the ICRB, and the models identify regions, such as Yellowstone, with particularly long FRIs.

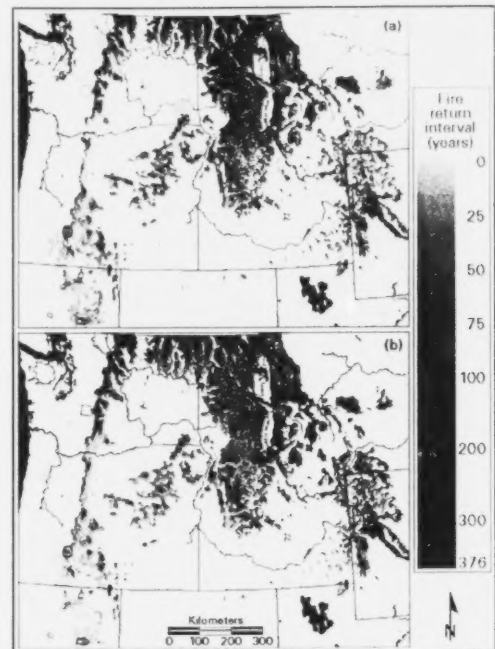


Figure 2: Predicted fire return intervals in the Columbia River Basin from 2 models: (a) all sites included (b) only high-quality sites included.

Within eastern Washington, fire interval distributions change with changes in spatial scale. At small scales (points), models identify an increased burning hazard with time-since-fire, presumably related to fuel build-up, whereas at larger scales the burning hazard is constant over time, suggesting that the fuel constraint no longer applies.

The lake sediment core from NCNP was 9.74 m, with an average resolution of 10 years per cm. Thus, we have a 9000+ yr record of fire and vegetation. A high concentration of charcoal and frequency of charcoal peaks in early Holocene sediments was followed by a decline in later Holocene sediments, beginning around 6800 years BP. Forest assemblages based on macrofossil conifer needles also differ from the early Holocene, in which subalpine fir and Douglas-fir are dominant, to the later Holocene, in which a diverse montane forest with more mesic species developed.

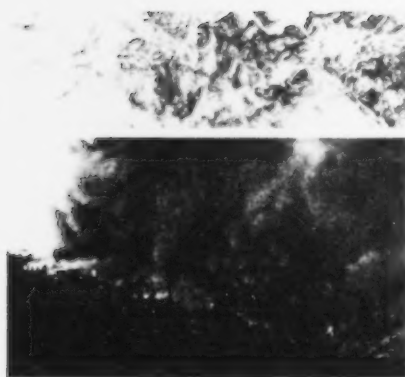
Our results are applicable to simulation efforts at multiple spatial and temporal scales. For example, coarse-scale landscape simulations can directly use our regional-scale fire frequency models. The fire-history models from eastern Washington can be applied both to short-term risk assessment and long-term projections of fire regimes and their effects on vegetation and fuel loadings. The temporal resolution and extent of our reconstructions from lake sediments, along with existing Holocene climatic reconstructions, allow us to link climate, fire, and vegetation across multiple temporal scales and quantify the historical range of variability over 9000 years. All 3 studies apply to

fire management by quantifying spatial and temporal variation in fire regimes.

References

- Daly, C. et al. 1994. *J. Appl. Meteorol.* 33:140-158.
- Heyerdahl, E.K. et al. 1995. Fire history database of the western United States. EPA Office Res. Dev. Report EPA/600/R-96/081. Washington, DC.
- Keane, R.E. et al. 1996. Simulating coarse-scale vegetation dynamics using the Columbia River Basin Succession Model CRBSUM. USDA For. Serv. Gen. Tech. Rep. INT-GTR-340. Rocky Mountain Research Station, Fort Collins, CO.

NOTES



POSTERS

Poster Presentations

- | | |
|---|--|
| Natural forest composition variability as an indicator of sustainable management | Alvarez, E., L. Bélanger |
| Using prescribed fire in boreal ecosystems: The EMEND experience | Bothwell, P.M., W.J. de Groot, C. McGuinty |
| Testing ecosystem management in the southeastern boreal mixedwood forest: The SAFE project | Brais, S., B. Harvey, Y. Bergeron, C. Messier, D. Greene |
| Modelling forest landscape disturbance by the mountain pine beetle and the effects of alternative management strategies | Fall, A., T.L. Shore, W.G. Riel, L. Safranyik |
| Interaction of spruce budworm and wildfire disturbance regimes at landscape scales in Ontario | Fleming, R.A., J.-N. Candau |
| Landscape modelling of forest dynamics and management for the evaluation of indicators in SELES | Fortin, M.-J., A. Fall, D. Kneeshaw, S. Yamasaki, C. Messier |
| Characterizing sub-boreal regimes in the Cariboo-Chilcotin region of central British Columbia | Francis, S., S. Skinner, D. Conly |
| The use of historical fire mapping in shaping harvest allocation design: Making fire emulation happen on the Hearst Forest | Graham, G., L. Quist |
| Comparison of vegetation structure at fire and cut edges: Can forest harvesting emulate natural forest boundaries? | Harper, K.A., D. Lesieur, P. Drapeau, Y. Bergeron |
| Natural disturbance-based management in the Lake Duparquet forest | Harvey, B., Y. Bergeron, A. Leduc, S. Gauthier, S. Brais |
| Does a gap-based silviculture system emulate natural disturbance dynamics in mixedwood forests? | Kneeshaw, D.D., M. Prévost |
| A comparison of the disturbance rates in shoreline areas of natural and managed forests in Northern Ontario | Landstrom, J.M., R.S. Rempel |
| The fire disturbance impact on the timber supply: where and when | Liu, J., C. Li, D. Campbell |
| C and N mineralization potentials for incubated soils from harvested and burned <i>Picea mariana</i> stands in northwestern Ontario | Luckai, N., N. Peterson, D.M. Morris |
| Emulating natural wildfire disturbances beyond the landscape level | McRae, D.J., T.J. Lynham, L.C. Duchesne |

A modeling attempt at characterizing the spatial impact extent of gaps	Ménard, A., P. Dubé, A. Bouchard, D.J. Marceau
Stand dynamics under different fire regimes in pine-oak forests of the Sierra Madre Occidental, Mexico	Park, A.D.
Predicting future forest landscape conditions and bounds of natural variation: A spatially stochastic modelling approach for the boreal biome	Perera, A.H., D. Baldwin, F. Schnekenburger, D. Yemshanov, K. Weaver
BFOLDS – A spatially explicit stochastic model to simulate boreal forest landscape dynamics	Perera, A.H., D. Yemshanov, F. Schnekenburger, K. Weaver, D. Boychuk
The nature of ecosystemic management: Postmodernism and plurality in sustainable forest management	Purdon, M.
Estimating historical range and variation of landscape patch dynamics: Limitations of the simulation approach	R.E. Keane, R.A. Parsons, P.F. Hessburg
Setting regional and management unit targets for forest composition and age class based on the concept of bounds of natural variation	Racey, G., K. Ride, T. Longpre, P. Elkie
Mapping fuels and fire regimes using remote sensing, ecosystem simulation, and gradient modeling	Rollins, M.G., R.E. Keane, R.A. Parsons
The effects of forest management, landscape structure, and weather on furbearers	Savage, D.W., I.D. Thompson, U.T. Runesson, J.A. Baker
Large-scale disturbances and forest landscape dynamics in mountain areas	Schumacher, S., H. Bugmann
Songbird communities in burned and logged stands in the canadian rocky mountains: implications for forest management	Stuart-Smith, K.
Analyses of major ice storm impact on hardwood forest dynamics using the forest simulation model SORTIE	Tremblay, M., C. Messier, D.J. Marceau
A decision-support tool to evaluate wood procurement cost for a wide range of harvesting scenarios	Valeria, O., L. LeBel, K. Lowell
Ecological indicators for assessing emulation of natural forest landscape disturbance through logging: A scale-defined procedural framework	Venier, L.A., J.L. Pearce, D.W. McKenney

(0.8k P.R., 02 04 15)
ISBN 0-7794-3063-8
ISSN 0319-9118

